RT-173: Helix

2017 Helix Technical Report

Technical Report SERC-2018-TR-101

January 16, 2018

Principal Investigator: Dr. Nicole A.C. Hutchison, Stevens Institute of Technology

Co-Principal Investigator: Dr. Dinesh Verma, Stevens Institute of Technology

Research Team:

Stevens Institute of Technology: Dr. Pamela Burke, Ms. Megan Clifford, Mr. Ralph Giffin, Mr. Sergio Luna, Mr. Matthew Partacz

Sponsor: Office of the Deputy Assistant Secretary of Defense for Systems Engineering DASD(SE)

The Systems Engineering Research Center (SERC) is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology.

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Office of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) under Contract H98230-08-D-0171 and HQ0034-13-D-0004.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The Helix team would like to thank all the organizations and individuals that participated in the project, offering their resources, time, and effort. This was critical to our research. Their active participation in the Helix interviews provided us data that was rich in both quality and quantity, which makes this research more valuable and useful to the participating organizations and the systems engineering community at large. To the organizations that have publicly shared information about their experiences with using *Atlas*, we owe tremendous thanks; without them, this document would not be possible.

We are most grateful to the Office of the Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), especially Kristen Baldwin and Scott Lucero, for their continued support, without which this research would not be possible. The International Council on Systems Engineering (INCOSE) and the National Defense Industrial Association Systems Engineering Division (NDIA-SED) are both valued partners in this research and we thank them, especially Courtney Wright, David Long, Bill Miller, and Don Gelosh.

We thank all former members of the Helix research team whose contributions have shaped our research over the years. In particular, we would like to thank Dr. Art Pyster, whose leadership and dedication since the beginning of the project were critical and instrumental to its success and who still champions and supports Helix.

I would also like to personally thank the current Helix team, who have helped tremendously to mature not only the project, but my own thinking and views on it. Pam, Ralph, Sergio, Megan, Matthew, and Dinesh, please accept my gratitude for your hard work and dedication.

Nicole AC Hutchison

Nicole AC Hutchison
Helix Principal Investigator

EXECUTIVE SUMMARY

This document summarizes the work done by the Helix team in 2017 and highlights the work planned in 2018. In particular, it provides details on:

- Additional analyses conducted by the Helix team
- Additional data collected by the Helix team
- The change in research questions, which are now:
  - **How can organizations improve the effectiveness of their systems engineering workforce?**
  - **How does the effectiveness of the systems engineering workforce impact the overall systems engineering capability of an organization?**
  - **What critical factors, in additional to workforce effectiveness, are required to enable systems engineering capability?**
- The three companion documents to this report developed by the Helix team:
  - **Atlas *1.1: The Theory of Effective Systems Engineers*** – (SERC-2018-TR-101-A) This is an incremental evolution of *Atlas* that reflects feedback from the community, additional analysis, and maturation of the team's thinking in 2017. In particular, *Atlas* includes minor updates on the values systems engineers provide, the roles systems engineers play, the proficiency model for systems engineers, and the personal characteristics of systems engineers. Henceforth, this will be referred to as "*Atlas* 1.1".
  - **Atlas *Career Path Guidebook*** – (SERC-2018-TR-101-B) This document provides analyses of the Helix dataset, providing common patterns in systems engineers' careers. The Guidebook also provides some insights on questions commonly asked of the Helix team around career paths and the team's responses. Finally, additional work on linking proficiencies to career paths has been completed and is reflected in the guide. Henceforth, this will be referred to as the "*Guidebook*".
  - **Atlas *1.1. Implementation Guide: Moving from Theory Into Practice*** – (SERC-2018-TR-101-C) Whenever *Atlas* is presented, there are many questions about how to take the theory and apply it in practice. The Guide provides examples from organizations that have implemented parts of *Atlas*, and guidance created by the Helix team based on many interactions with organizations around implementation as well as the extensive Helix dataset. Henceforth, this will be referred to as the "*Implementation Guide*".

The future vision for *Atlas* includes developing a theory of systems engineering capability which is predicated on the hypothesis that an appropriately skilled systems engineering workforce supported by culture, governance, and infrastructure will deliver an effective systems engineering capability.

1 Background and Introduction

The Systems Engineering Research Center (SERC), a University Affiliated Research Center (UARC), set up by the U.S. Department of Defense (DoD), responded to the systems engineering workforce challenges by initiating the Helix Project to investigate the "DNA" of systems engineers, beginning with those who work in defense and then more broadly. The US Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), the International Council on Systems Engineering (INCOSE) and the Systems Engineering Division of the National Defense Industrial Association (NDIA-SED) jointly sponsor Helix. To ensure Helix delivers the greatest value and to help Helix obtain access to the necessary data, Helix formed the Helix Advisory Panel (HAP) with representatives primarily from those three sponsor organizations. Helix has held three annual workshops with a broad set of representatives from across government, academia, and industry.

Helix is a multi-year longitudinal research project, which has gathered data from many organizations with DoD and the Defense Industrial Base (DIB) through a combination of techniques, including interviews with hundreds of systems engineers. In 2014, Helix began to reach beyond DoD and the DIB, to gather data from other types of organizations as well, including non-defense organizations in the US and non-US organizations. Version 0.25 of *Atlas* was also published in 2014. *Atlas* identifies the key variables that impact a systems engineer's effectiveness – positively or negatively – and provides, as much as possible, details on how these variables impact effectiveness.

During 2015, Helix expanded its data collection by conducting interviews with non-DoD organizations as well; matured *Atlas* into the next versions, *Atlas 0.6*; defined and analyzed the career paths of systems engineers; and did implementation trials of *Atlas*.

During 2016, the team generated *Atlas 0.6* and *Atlas 1.0. Atlas 1.0* reflects the results of analysis of in-depth interviews with 287 individuals. Most of these individuals were systems engineers, though approximately 10% of the sample was comprised of individuals who work with systems engineers – organizational leaders, classic engineers (electrical, mechanical, software, etc.), and program managers. In 2016 the Helix team also worked on implementation of *Atlas* with a number of organizations and lessons learned from those activities are captured here.

1.1 The Helix Project

The US Department of Defense (DoD) and the Defense Industrial Base (DIB) – contractors that develop and deliver systems to the DoD – have been facing major systems engineering challenges in recent years (e.g. GAO 2008, 2011, 2012, 2013). Mission requirements are evolving and they demand ever more sophisticated and complex systems (e.g. Boehm et al. 2010; INCOSE Technical Operations 2007; Davidz 2006; Davidz and Nightingale 2007; Frank et al. 2007; INCOSE 2014); the tools, processes, and technologies that systems engineers must master keep changing more rapidly (e.g. Frank 2006); and budgets and schedules are being compressed dramatically. An additional concern is that thousands of systems engineers in the defense workforce are nearing retirement; they will take with them hundreds of thousands of staff-years of experience (DoD 2013).

Organizations have responded to these challenges in a variety of ways, such as offering extended training and education to their current workforce or systematically seeking to select specialty engineers with the potential to become systems engineers and incorporating them into the ranks of systems engineers. Unknown is whether these actions are producing the desired results because there is no common understanding of the diverse roles that systems engineers play, how they are selected and evaluated, what competencies are most important for different roles, how to evaluate effectiveness, or how experiences impact effectiveness. These and many other insights will be critical to maintaining and growing the systems engineering workforce in the US DoD and DIB.

1.2 How is *Atlas* Different from Helix?

Helix is the name of the overarching SERC project. Helix has been examining what makes systems engineers effective for over four years. As a project, Helix has created many different deliverables or products. The primary product of Helix is *Atlas: The Theory of Effective Systems Engineers*. This document represents *Atlas 1.0* – expected to be mature enough for individuals or organizations to use without direct help from the Helix team. It is a standalone document to detail the contents of *Atlas*.

This document does *not* contain all of the research that led to the development of *Atlas 1.0*. Instead, the detailed research results and how they led to *Atlas 1.0* are contained in the companion Helix Technical Report (SERC-2016-TR-118). Individuals or organizations that want not just to use *Atlas* but to also understand the rationale and methodology behind its development should reference the Technical Report. Several earlier published Helix papers and technical reports are also referred to throughout this report. The reader is not expected to read the earlier technical reports or any of the other Helix papers or reports, in order to understand *Atlas 1.0*.

In addition, there are tools that an individual or organization can use to support self-assessment using *Atlas*. The paper-based tools are contained in the Appendices of this report. The team has also developed more easily tailored Excel-based tools, which can be found on the Helix page of the SERC website (http://www.sercuarc.org/projects/helix/).

The relationship between Helix, *Atlas*, the Technical Reports, and the tools is illustrated in Figure 1.

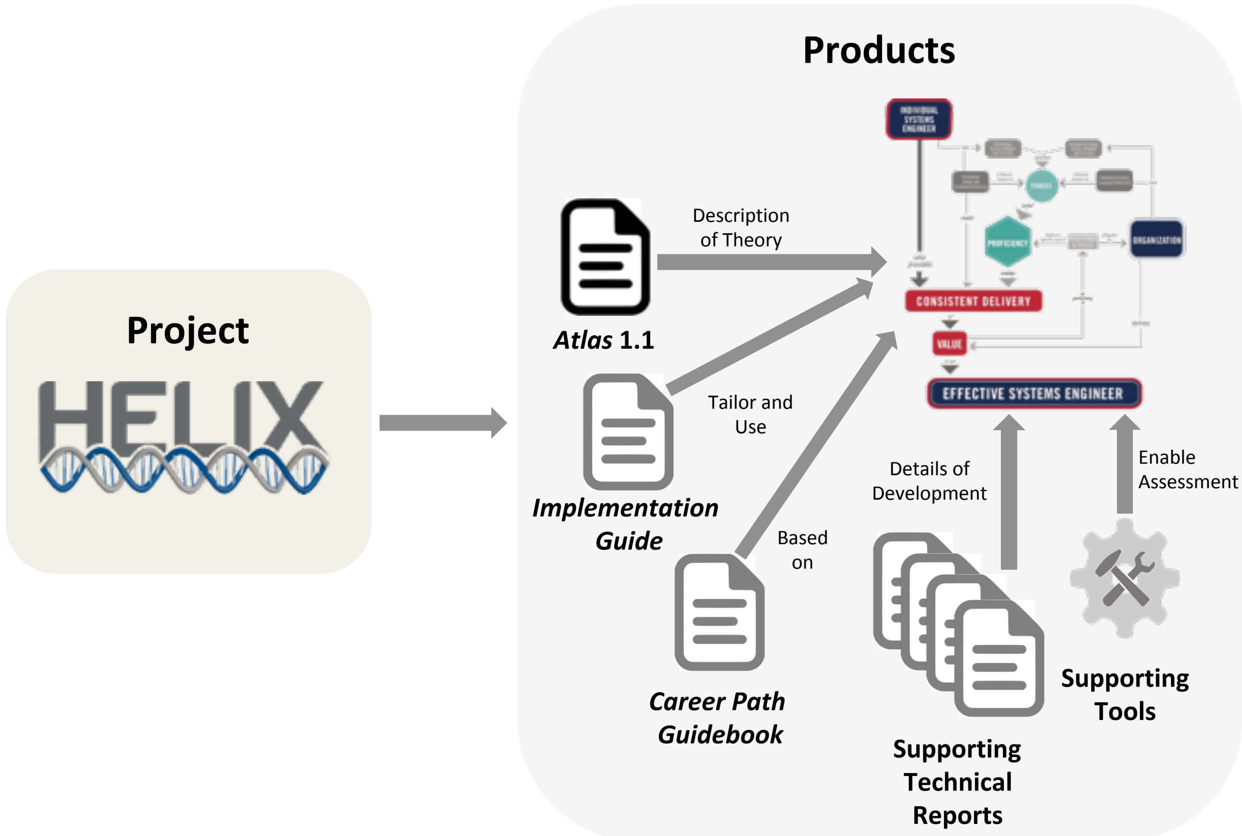

Figure 1. Relationship between Helix and Atlas

1.3 Incremental Development of Atlas

The Helix project used an incremental approach to develop *Atlas*. This approach was designed to enable publication and use of aspects of *Atlas* as they became appropriately mature, while maintaining the expectation that *Atlas* would become more mature over time. The increments were:

- ***Atlas 0.25***: The first draft of *Atlas* based on work done in 2014 was published as *Atlas 0.25* in November 2014. It included key elements that explain the effectiveness of systems engineers, and a preliminary explanation of the relationships between those elements. The structure and variables of the proficiency model were also included, along with some initial analysis of career paths.

- ***Atlas 0.5***: Based on subsequent work done in 2015, *Atlas 0.5* was published in December 2015. It reflected further understanding of the elements of *Atlas* and their inter-relationships. Significant new work was done in the area of career paths and *0.5* incorporated initial efforts to use *Atlas* to assess the level of proficiency of systems engineers. *Atlas 0.5* was mature enough for an individual or an organization to use and gain valuable insights with some guidance from the Helix team.

- ***Atlas 0.6*:** Was an incremental improvement to *Atlas 0.5*. It contained additional detail and analysis for areas that were less mature in 0.5, namely: mentoring, personal initiatives, and organizational initiatives. *Atlas 0.6* was not created as a stand-alone document, but rather as a supplement to 0.5.

- ***Atlas* 1.0**: Atlas 1.0 included a more complete description of the elements of Atlas and their inter-relationships. Atlas 1.0 is believed to be mature enough for independent deployment and assessment by individuals and organizations with little or no guidance from the Helix team. In addition, the frameworks presented in Atlas 1.0 have been validated using data from outside the US DoD, and therefore is believed to be applicable to systems engineers in a variety of domains. This is intentional. Though the initial impetus for the work was based on the needs of the US DoD, the Helix team believes that a more generic framework which benefits all systems engineers, regardless of domain, is both more beneficial to the community at large and, ultimately will benefit the US DoD by setting consistent expectations for practitioners across domains.

- ***Atlas* 1.1:** This is an incremental update to *Atlas* that reflects the teams' learning in 2017.

1.4 About This Document

This technical report is written as a standalone document, presenting version 1.0 of *Atlas: The Theory of Effective Systems Engineers*. Several earlier published Helix papers and technical reports are referred to throughout this report. However, the reader is not required to read the earlier technical reports or any of the other Helix papers or reports, in order to understand *Atlas 1.0.*

Readers should note the following about the report:

- Throughout the report, the term 'Helix' is used to denote either the project or the team that performed the work in developing *Atlas*.

- The *Guide to the Systems Engineering Body of Knowledge* (SEBoK) is used across the report as the primary source of consistent terminology and definitions relevant to systems engineering. (BKCASE Editorial Board 2016)

- All insights and observations are presented only in an anonymous, aggregated manner. Individuals or organizations that participated in the Helix project are neither named nor are they identifiable from this report.

The report is organized as follows:

2 Methodology

This section provides detail on how the Helix project has been structured since its inception. This includes overarching methodology, details of analytic approaches, and detail about the dataset. The organization of Section 2 is as follows:

- The overarching philosophical approaches to the research (Sections 2.1-2.3),
- The detailed analysis approaches for the research (Sections 2.4 and 2.5),
- A summary of the methodology used for a master's capstone project on Helix (2.6),
- An overview of the dataset (Section 2.7), and
- Guidance on how to interpret the data, including limitations of the dataset (Section 2.8).

2.1 Research Philosophy

Helix is primarily a qualitative study, with the primary means of data collection being interviews with systems engineers. From 2012-2013, the Helix team focused on a mixed-methods approach (Creswell and Plano 2011), combining the development of basic research questions with a grounded theory approach. Grounded theory was developed in the social sciences as a method for developing theory that is grounded in data that is systematically gathered and analyzed. (Goulding 2002) This approach allows the data itself to drive points of further inquiry, guide categorization, etc.; rather than starting analysis with an existing framework, all of the data is reviewed holistically and any potential areas of interest are coded. Over time patterns emerge and these guide further data collection and analysis. The development of driving research questions makes the Helix project mixed method as opposed to pure grounded theory.

When performing initial data coding, the Helix team coded all data, not making suppositions about which data would prove "important". The team also compared data collected against the existing literature where possible. For example, as systems engineers defined the activities that they perform, the team collected and organized the raw data but also compared it to the "Twelve Roles of Systems Engineers" defined in (Sheard 1996).

This approach still reflects the philosophy of Helix: *Atlas* 1.0 is largely a reflection of the data, using the grounded theory principles to "let the data speak".

2.2 Overarching Research Methodology

The research methodology adopted for Helix research may be considered to be a modified grounded theory based approach, employing qualitative and quantitative research methods.

During 2013 and 2014, Helix primarily focused on data collection from DoD and DIB organizations through semi-structured in-person interviews with individuals or small groups, continually refining the interview questions and process. Follow-up interviews were conducted by telephone with most of the participants. Analysis of the data to address the Helix research questions offered insights into the effectiveness of systems engineers and led to the development of an early version of *Atlas* that was published in November 2014. During 2015, data collection was expanded to organizations outside of DoD and DIB, and *Atlas 0.25* was validated and improved upon, leading to the next version, *Atlas 0.5*, published in December 2015.

The Helix project adopted a grounded theory approach because it did not presuppose any specific theory or propose any hypotheses at the start of the project. Grounded theory was developed in the social sciences as a method for developing theory that is grounded in data that is systematically gathered and analyzed (Goulding 2002). Rather than beginning with a hypothesis, the first step was data collection. This approach is unusual in engineering research, where a researcher traditionally begins with a theoretical framework that he or she applies to the phenomenon to be studied. In the Helix project, the data collected from the many semi-structured interviews were marked up with codes that were grouped into concepts, that led to the identification of constructs and categories that formed the building blocks of *Atlas*. This approach minimized any bias that might be introduced by the researchers, instead allowing the large data set collected through the Helix project to drive theory development. Having established a preliminary theory of effective system engineers and proficiency model of systems engineers, data collection and interviews conducted during 2015 focused on validating *Atlas*, and refining the theory towards developing *Atlas 1.0* in 2016.

Qualitative research aims to create or discover what things are made of, and what is created or discovered are called constructs. Qualitative research is useful for obtaining insight into situations and problems on which one has little knowledge a priori. This method is commonly used for providing in-depth descriptions of procedures, beliefs and knowledge, including the opinions of respondents about particular issues; detailed data is gathered through open-ended questions. Data collection for the Helix project and subsequent analysis of the data was primarily done employing qualitative research methods; appropriate software tools were used to support coding and identification of constructs.

Quantitative research begins once initial constructs are in hand. It attempts to gather data by objective methods to provide information about relations, comparisons, and predictions. In the context of the Helix project, quantitative research was performed once initial constructs for demographics of systems engineers, their organizations, and their career paths were established. Data was collected from their resumes, as well as through pointed questions during interviews. Quantitative analysis continues to be performed on various elements of *Atlas* that were developed based on qualitative research, particularly on the proficiency model.

2.3 Helix Research Process

The Helix research methodology discussed in the preceding section was deployed using the research process illustrated in Figure 2 below. The Helix research process consists of seven major steps:

A. Preparation for Data Collection
B. Data Collection
C. Data Analysis
D. Methodology Review
E. Theory Development
F. Publishing
G. Validation, Feedback & Deployment

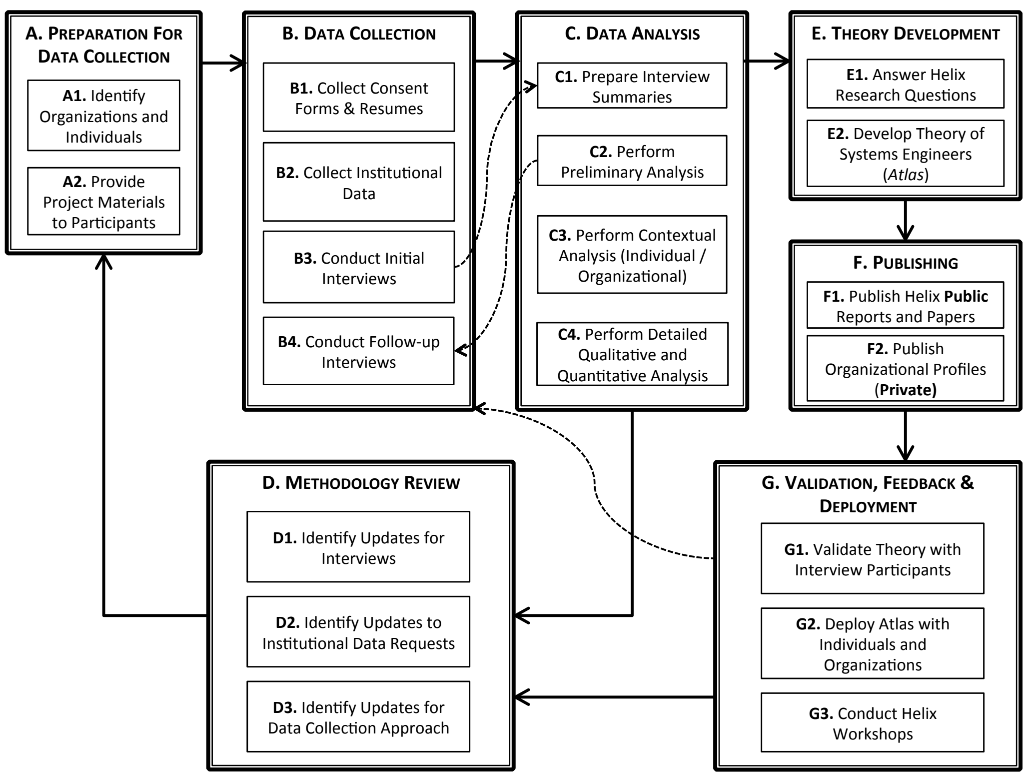

Figure 2. Helix Research Process

The focus of Helix in 2013 was on executing the loop **A-B-C-D-A** multiple times with different organizations. The loop **B-C-B** was executed a few times when follow-up interviews were conducted with some organizations. During 2014, in addition to performing the **A-B-C-D-A** loop with new organizations, steps **E-F-G** were executed that led to initial the development of *Atlas 0.25*. In 2015, much effort was concentrated in executing step **G**, as well as executing the loop **A-B-C-D-A** with commercial non-DoD organizations as well as with many participants who did not consider themselves to be systems engineers. In 2016, the primary efforts were focused on executing step **G**, which included supporting organizations as they determined how to implement *Atlas* and conducting extensive outreach with the systems engineering community. This has led to further refinement of Atlas in step **E**, leading to step **F** - the publishing of *Atlas 1.0*.

In 2017, the Helix team executed loop **A-B-C-D-A** with three new organizations. The loop **B-C-B** was executed by examining the existing dataset and comparing it to new data collected. Steps **E-F-G** were executed leading to the updated to *Atlas* 1.1 and the development of this report and the two companion documents.

2.3.1 Preparation for Data Collection (A)

Since Helix research is based on a grounded theory approach, preparation for data collection was the first step executed in the project. Initially, organizations from within the US DoD and other organizations from the DIB were identified for data collection; also, the primary focus was on systems engineers in these organizations (**A1**). As Helix progressed, in 2015 other commercial organizations from non-DoD sectors such as healthcare and information technology were identified for data collection. The latest reports and papers published from the Helix project were provided to potential interviewees (**A2**). Based on their willingness to participate in Helix interviews, the organization makes final decisions on who participates in Helix interviews. In 2016, the primary focus has been on additional publication and on assisting with the implementation of *Atlas* at several organizations. These efforts have helped the team understand where the theory needed adjustments to make it easier to utilize.

In 2017, there was a shift in research questions from previous years (see section 3.1.1). With a different focus to the research, the team invested time in developing new questions and guidelines for data collection (see Appendix B and Appendix C). The updated research questions were critical to enable the Helix team to collect new data that will bridge the previous results with new areas of inquiry.

2.3.2 Data Collection (B)

The first round of data collection with an organization is typically through a site visit to the organization, where in-person interviews are conducted. Typically, there will be 2 or 3 Helix interviewers and anywhere from 1 to 6 interviewees in a single 90-minute interview session (**B3**). Following approved research protocols, a signed consent form is collected from the participants before conducting interviews; resumes are also requested from all participants (**B1**). Any available organizational data that will provide insights into the systems engineers in the organization and how they are structured within the organization are gathered before and during the site visit (**B2**). In 2015, as the project expanded to include non-DoD participants, initial interviews were conducted over telephone when the number of participants from an organization was very low. All follow-up interviews were conducted over telephone (**B4**). In 2016, there have been no additional interviews. Instead, the team has focused on analysis of the data collected and on assisting organizations with the implementation of *Atlas*. Data gathered in 2016 was focused, therefore, on an issues identified with implementation and determination of whether those issues reflected a weakness in *Atlas* to be addressed or whether they were a reflection of the unique environment of a given organization.

Data collection in 2017 was focused on gathering new data to help fill gaps in the existing dataset, focusing on organizational culture, governance, and infrastructure, and how these impact systems engineers.

2.3.3 Data Analysis (C)

The first step in data analysis is to prepare summaries of all interview sessions (**C1**). Where interviewees permit audio recording, transcripts are first created then cleaned and prepared for further analysis. If recording is not permitted, summaries are created from the notes taken during the interviews. Preliminary analysis, typically not employing significant effort on using analysis tools, is performed to quickly identify additional questions to be asked or additional data to be collected during follow-up interviews (**C2**). Since 2014, significant research effort has been put into performing contextual analysis on an individual, particularly on her career path (**C3**). Detailed qualitative and quantitative analyses, using software tools as necessary, have been performed on the large amounts of data that have been collected through Helix interviews (**C4**). These analyses make significant contributions to theory development efforts (**F**).

2.3.4 Methodology Review (D)

Data collection and analysis is being performed iteratively, as Helix continues to identify and visit organizations. After any site visit and before the next one, a review is conducted to identify any updates to the interview questions or process (**D1**). While much organizational data is desired for Helix analysis, not all information is being made available within an organization in a form that may be readily shared with Helix researchers. Based on experiences with organizations, the nature and content of organizational data requested has been regularly updated (**D2**). Based on significant data analysis and theory development that was performed in

2014, the data collection approach was revised from being a semi-structured interview to being a discussion on assessing the proficiencies of individuals and analyzing their career paths (**D3**). Feedback received from individuals and organizations on the Helix reports (**G**) also influenced the updates performed in step **D**. In 2015, work on broad implementation has identified areas has been the focus. However, if additional in-depth interviews are conducted in future, the approach of reviewing findings and conducting interviews around existing frameworks is expected to remain consistent.

2.3.5 Theory Development (E)

Analysis performed on data collection during 2013 focused primarily on answering the Helix research questions at a broad level (**E1**). Since 2014, the focus of analysis has been to develop *Atlas* (**E2**). Version 0.25 of *Atlas* was published in November 2014. *Atlas 0.5* was published in December 2015 and an incremental improvement, *Atlas 0.6* was published in April 2016. Refining this theory, and packaging it for independent assessment and deployment by individuals and organizations has been the focus of research efforts in 2016. Additional data collected and continued work with organizations implementing *Atlas* culminated in the development of *Atlas 1.1*.

2.3.6 Publishing (F)

Publishing reports and papers for public consumption is a key objective for Helix research (**F1**). All results and observations reported in Helix publishing are done in an anonymous aggregated manner. Nothing published by Helix is traceable to any particular individual or to an organization. Organizations may choose to reveal their participation in the Helix project, but they are not listed in any Helix report. In addition, peer-reviewed conference and journal papers continue to be published for wide dissemination of Helix results. While some form of an organizational profile is created as part of internal Helix analysis, in some rare cases, a private report is provided to participating organizations upon request to support their systems engineering workforce development efforts (**F2**).

A complete list of Helix-related publications can be found in Appendix A.

2.3.7 Validation, Feedback & Deployment (G)

Since publishing *Atlas 0.5*, step **G** has become the primary focus of the Helix process. In implementation efforts conducted in 2016, the *Atlas* theory and proficiency model have been validated in a number of ways. During 2015, Helix began deploying *Atlas* with specific organizations in an attempt to use *Atlas* to establish the proficiency levels and career paths of participants and to be able to discuss ways to develop their careers in the future, towards achieving targeted levels of proficiencies required for particular senior positions within the organization (**G1**). In 2016, Helix helped a few organizations think critically about how *Atlas* could be implemented – including any modifications to fit the organizational context. (**G2**) The result of this work has helped the Helix team to clearly identify where tailoring of *Atlas* is expected versus where *Atlas* is expected to remain very consistent regardless of the organization, domain, etc. The primary expectations for tailoring are highlighted in the discussion of implications for use of the proficiencies.

The first Helix workshop was held in July 2014, with participation of representatives from DoD, academia, and industry, including representatives from organizations that participated in Helix interviews. Feedback from the workshop significantly shaped *Atlas 0.25*. The second Helix workshop was held in August 2015 and reinforced the relevance and potential value of *Atlas* to a variety of systems engineering organizations. The third Helix workshop, an early adopter's workshop, was held in September 2016 and provided participants the opportunity to examine *Atlas* in detail and even allowed participants the opportunity to use the tools. The fourth Helix workshop was held in October 2017 and focused on the methods that had been utilized to date in employing *Atlas* as well as research updates in 2017 (**G3**).

2.4 Qualitative Analysis

The Helix research methodology discussed in the preceding sections was deployed using the analysis processes described below.

2.4.1 Coding

The interview dataset comprises nearly 6,000 pages of transcripts and summaries from 287 individuals. In order to make sense of such a large quantity of data, the Helix team uses qualitative data analysis, primarily through data coding. Coding is "a systematic way in which to condense extensive data sets into smaller analyzable units through the creation of categories and concepts derived from the data." (Lockyer 2004) Codes can be layered, and evolve over time, as explained below. When developing a theory, as in the development of *Atlas*, categories and codes are generated *after* examining the collected data, aligning with the grounded theory approach. (Bourque 2004 and Lockyer 2004) The main type of coding done by the team so far is called "open coding", the purpose of which is to break down, compare, and categorize data (Strauss and Corbin 2014).

The team has used two techniques for coding: auto coding and manual coding. "Auto coding" is only the first stage in parsing the information contained in transcripts and is not fully automated despite its name. Instead, as the team reviews and cleans each transcript, headings are added to the source documents to block out a large area of text as addressing a particular topic, such as personal characteristics, mentoring, experiences, etc. When the documents are imported into the qualitative analysis tool, NVIVO, the tool then automatically codes all text under that heading for the given subject. The team, then can pull up all auto coded text related to personal characteristics, for example, from across the entire data set and examine it at once. This allows a more consistent look at the related data that can then evolve more quickly, allowing the team to identify patterns that occur across data.

Auto coding is a useful approach, but has its drawbacks. One of the strengths of the coding approach is that codes can overlap - individuals may discuss several issues together and researchers can layer multiple codes together. Not only does this help to give a true characterization of the data, but common patterns in overlaps may provide useful insights. For example, the proficiency of big picture thinking was often discussed simultaneously with several of the values that systems engineers provide. This helped explain, for example, the relationship between big picture thinking as a critical skill and how that approach can provide value on diverse teams. But when using auto coding, layered codes are not possible; in the example of big picture thinking and value, the text would be tagged either as "Personal Characteristics" or "Proficiency" - not both. Since auto coding is only the first step, there are additional opportunities to create the layering and complexity that reflects the nature of the data. However, auto coding does limit the researcher to make a choice about what is most important or most prevalent in a section at the outset, which raises the risk that important relationships could be missed later. The other drawback to auto coding is that categories had to be developed and applied to all data and, therefore, could not happen early in the project. The team agreed to a limited set of categories, largely aligning with elements of *Atlas 0.5* published in 2015.

If auto coding was not used – for example, if there were a new area of inquiry, meaning that no headings had previously been identified and applied – then the team had to manually review and code all ~6,000 pages of data. Though keyword searches could be used, there was a risk that data could be missed if only keyword searches were used. For this reason, the team used a variety of keyword searches related to a given topic as well as a scanning read of a transcript when doing the initial pass for manual coding. For example, when looking for information on training, keywords included, "train," "course," "class," "learn", and "study". Once the initial coding was complete, this is essentially equivalent to auto coding in terms of level of depth.

Additional codes were then added to this subset of the data to further clarify the patterns. For example, a total of 30 individual personal characteristics were identified by participants. Some of these, in the discussion, were directly linked to the values that they helped to provide – these sections were double coded for both the characteristic and the value. Once all of the data had been analyzed, the team identified a reportable threshold – for example, for personal characteristics there were 141 excerpts and 30 characteristics.

Individual characteristics were mentioned anywhere from 15 times to only a single time across the excerpts. While none of the characteristics is “wrong”, it was also not useful to simply provide a laundry list of items, particularly those that were only mentioned once across such a large dataset. It was more useful to first identify whether there were any relationships between items that might help identify areas of importance. This was done by comparing overlaps between codes. In other words, a single excerpt might be coded for multiple characteristics that were discussed together. By examining how often characteristics were cross-coded, it helped to identify relationships that participants believed are important across organizations. For example, in terms of personal characteristics, ambition and internal motivation often were discussed simultaneously, which is why they are grouped together in *Atlas*. Figure 3 provides an example of the coding comparisons conducted by the Helix teams. The higher the bars, the higher the overlap in coding between characteristics. This provides Helix with insight into relationships between and patterns around characteristics based on how interviewees discussed them.

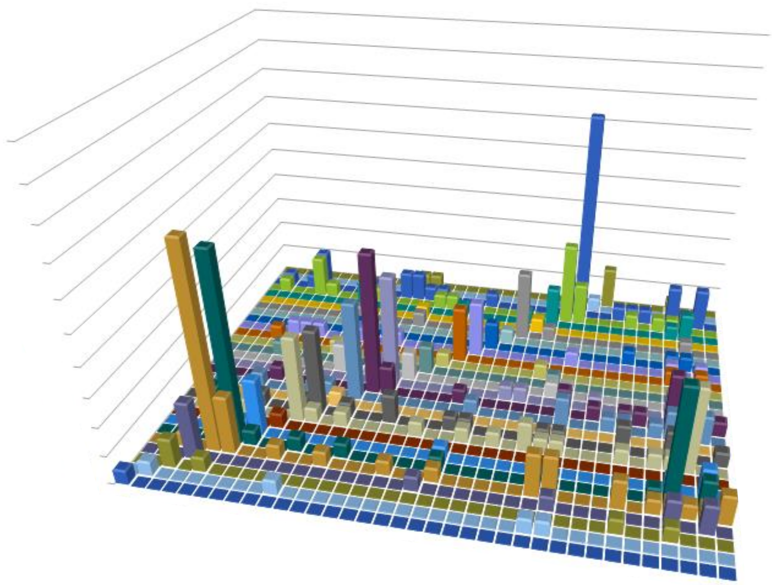

Figure 3. Example of Coding Relationships

When reporting, there was also a natural cutoff – again, in the example of Personal Characteristics, any characteristic mentioned in more than 6% of the excerpts. This was a natural threshold because the next cluster of characteristics occurred in approximately 1% or less. Items above the 6% threshold were reported in *Atlas 0.5*; items below it were not. However, because the coding structure remains in place, as additional data is added, if other characteristics become more prevalent, then they may be added to the next iteration of Atlas. Personal Characteristics were also presented in the descending order by the number of excerpts in the dataset; e.g., "self awareness" is listed first because it was discussed in the highest number of excerpts.

2.4.2 Tool Support and Combining Qualitative Analysis with Demographics

To support the its analysis, the team has imported all of the data into NVIVO (QSR International 2016), a powerful and popular commercial qualitative analysis tool. NVIVO allows the team to code text as well as overlay additional information and identifiers about the sources. This replaces tools used early in the project, namely a combination of Dedoose (Dedoose 2016) and Microsoft Excel, which proved insufficient to handle the volume and diversity of data required. In NVIVO, the sources are tagged with a code for the organization in which the individual worked at the time of the Helix interview, and then each organization is linked to characteristics such as whether it is government or commercial; whether defense, healthcare, transportation, etc.; and how systems engineer are organized, e.g. embedded, matrixed, etc. As much as possible, each comment is also tagged for the individual who made it, though in the summaries from the earliest interviews, there are a few exceptions. Each individual, again, has several characteristics, including gender, whether they are a systems engineer or a peer, and some results of the Helix career path analysis.

2.5 Career Path Methodology

In addition to the analysis of interview data, the Helix team developed a method for analyzing and visualizing the career paths of systems engineers. The career path method presented here supplements the qualitative data analysis described earlier with more quantitative information about an individual's career. This analysis was conducted for 181 systems engineers[1] from a dozen organizations. The initial data collection for career analysis was conducted by:

- Reviewing the resumes submitted by each individual, including chronology, organizations, position titles, and all descriptive text provided within the resumes;
- Reviewing interview transcripts and notes to add detail to the resume data;
- Reviewing the preliminary results during follow up interviews to clarify analysis. Individuals self-selected whether or not they would like to participate in follow-up interviews; roughly half of the individuals in the career analysis sample have participated in follow-up interviews; and
- Comparing the career paths with existing Helix research on the proficiencies of systems engineers and how career path elements may relate to these proficiencies. (Pyster et al. 2014b)

Using this approach, the Helix team developed a method to examine experiences and a common framework to capture, analyze, and visualize career paths. The self-assessment tool(s) provided to individuals participating in Helix to create their own career paths, including their proficiencies over time, are available in the *Atlas* 1.1.

2.5.1 Characterizing a Systems Engineer's Experiences

Experimental literature on experiences has primarily focused on two metrics for experience: time (e.g. Ford et al. 1993; Schmidt et al. 1986; Firth 1979; Davidz 2006) and the frequency of times a specific task or activity of interest was performed (e.g. Stuart and Abetti 2002). Additional literature classifies human subjects based on their experiences – which is subtly different than classifying the experiences themselves – often using a combination of time and the frequency of tasks performed. This approach may also include considerations for specific roles played (e.g. Stuart and Abetti 2002, Kor 2003, Kirschenbaum 1992). Additional literature in the field of systems engineering, such as Sheard's "Twelve Systems Engineering Roles" (1996) or the *Graduate Reference Curriculum for Systems Engineering (GRCSE)* (Pyster et al. 2012)

[1] The interviews for all systems engineers in the Helix study are included here. However, the resume data was not provided for some of these individuals, and not all resume data was sufficient to complete each type of analysis. In general, the career analysis sample is N=157. Where the analysis looks at a subset of the sample or where individuals were eliminated from analysis for insufficient data, the sample size (N=x) is provided in the text.

indicate, though, that the characterization of experiences is critically important to understanding how experiences enable growth.

The first challenge was to determine a common “unit of measure” for experience. Though time is common, it was not easily used in the data available. For example, if someone described a position they held over a five-year period, they did not explain the portion of time taken up by the activities they performed over those five years. In addition, several individuals submitted information on their careers that included detailed descriptions, but did not include markers for chronological time. Because of these data limitations, the Helix team chose to use a **position** as the unit of measure for experience.

Based on both the literature and the Helix data itself, each position has several characteristics:

- **Relevance:** A ‘relevant’ position is one that enables a systems engineer to develop the proficiencies critical to systems engineering.

- **Position:** Every systems engineer who is employed at an organization fills a position that is established by the organization; that organization also defines the roles and responsibilities to be performed. Helix considers position as a ‘unit of measure’ for experience, since most of the characteristics of experience are in the context of the position that is held. A ‘systems engineering’ position is one where the individual’s primary focus was on systems engineering activities.

- **Chronological Time:** The amount of time spent in any particular position or in performing a role.

- **Number of Organizations:** The number of different organizations that an individual has worked at, not counting internal movement within an organization across departments or divisions, reflects the variety of types of experiences that one may possess.

- **Organizational Sectors:** There are many differences in the general characteristics of an organization based on its sector. In *Atlas*, three organizational sectors are identified: government, industry, and academia.

- **Roles:** A role is a collection of related systems engineering activities. Roles were identified based on the activities consistently performed by systems engineers. There are 16 roles identified in *Atlas*, as described in Section 3.5, below.

- **Lifecycle Phases:** Generic systems engineering lifecycle phases considered in *Atlas* are based on the lifecycle phases in the *Guide to the Systems Engineering Body of Knowledge (SEBoK*). (BKCASE Authors 2015)

- **Systems:** There are many aspects to the types of systems on which a systems engineer could work. Working across these different categories provides valuable experience to an individual systems engineer.

- **Domain:** This is the primary area of application for the systems being worked on. However, there are many domain categorizations; some domains also relate to industry sectors.

- **Type:** Product systems, service systems, and enterprise systems are three major types of systems, depending on the nature and composition of the system of interest. System of systems is another paradigm in systems engineering, and could be a combination of one or more types of systems.

- **Level:** A systems engineer could work on various levels of a system: component/element, subsystem, system, and platform or system of systems.

By using the data available for each individual, the characteristics of each position played and the order that they played them can be identified. Looking for patterns across the Helix data set, this information can be used to develop a preliminary understanding of how career paths shape proficiency.

The ways in which positions were categorized were pulled from existing literature wherever possible. For example, a systems engineer working in the commercial sector of a company may define life cycle in different terms than those used by a US Department of Defense systems engineer. To normalize the discussion, the definition of life cycle stages from the *Guide to the Systems Engineering Body of Knowledge* (SEBoK) was used; the interviewee's own words and phrasing were compared with the descriptions of life cycle stages in the SEBoK and categorized appropriately. (BKCASE Editorial Board, 2014) Likewise, the roles played by the interviewees were based on Sarah Sheard's "Twelve Roles of Systems Engineers" (Sheard 1996), although roles have been added to reflect what was seen in the data. Where existing literature was not available, categories were created that reflect the character of the data.

2.5.2 Characterizing a Systems Engineer's Education

Education plays two key roles in the development of systems engineers. First, it provides the foundation knowledge to support engineering-related work. Typically, this takes the form of undergraduate education in an engineering discipline, technical field, or physical science. Second, graduate level education is an avenue to develop more advanced skills, explore more in-depth knowledge, and help systems engineers grow as they move through their careers.

The characterization of education was much more straightforward than the characterization of experiences. For each systems engineer in the sample, the team recorded:

- **Chronological Time:** The date of the completion of the degree program.

- **Type of Degree:** This is the level of education an individual achieved. The categories used were: bachelor's, master's, and doctor of philosophy (PhD). For this analysis, only education that resulted in a degree was recorded. Individuals did receive graduate certificates or took individual courses, but there was not enough data to draw any meaningful conclusions. Also, if a degree was in progress but not completed, it was not recorded.

- **Field of Study:** The primary discipline on which the individual's education was focused. These were initially recorded as reported. Over time, categories of related fields of study were created.

All systems engineers in the Helix sample held at least a bachelor's degree and the majority – 58% – held at least a master's degree.

2.5.3 Identifying Key Positions

A third aspect of career paths are the key milestones for a systems engineer's career. The Helix team focused on major steps or changes in a systems engineer's positions. A ***position*** is equivalent to the roles and responsibilities associated with an individual's title. Organizations will define what roles and responsibilities each position contains and *position* descriptions may not translate across organizations. The key positions identified for systems engineer included:

- **First systems engineering position.** This was self-identified by participants as the first position in which systems engineering responsibilities were the *primary focus* of a position, though they may have non-systems engineering responsibilities as well. This was often difficult to identify, because participants indicated that their roles often transitioned gradually and it was hard to identify when they officially became systems engineers, especially because so many never had that specific title. The Helix team recorded this information in whatever way it was provided by participants. In a few organizations, the hierarchy and structure for becoming a systems engineer was much more well-defined, and for individuals in those organizations, the transition to systems engineer was more easily identified.

- **Chief systems engineering positions.** A chief systems engineer (CSE) is someone who has formal responsibility to oversee and shepherd the technical correctness of a system, often coordinating with many other systems engineers who have smaller scopes of responsibility. These milestones are any positions in which an individual acted as a CSE, *regardless of their title within their organization*.

- **Project manager positions.** A project manager is someone who has formal responsibility to oversee the programmatic aspects of a system, generally focused on budget and schedule. Project management responsibilities sometimes overlap with SE responsibilities, particularly those around planning and management; in some instances, a CSE may also function as a PM.

These milestones are important for understanding how the nature of a systems engineer's work has changed over time. It also gives insights into how quickly an individual progresses through different stages of her career. By comparing these patterns across individuals, common ranges of progression can be identified, as can outliers. For example, among the CSEs discussed in this paper, one individual became a CSE only 8 years after completing his undergraduate degree. However, only 12% of CSEs gained their first CSE position within 10 years after entering the workforce; therefore, this is an outlier rather than typical for CSEs.

2.5.4 Assessing Proficiency

Interviewees were asked about not only their common activities but what they believe were the critical knowledge, skills, abilities, behaviors, and patterns of thought (cognitions) that enable them to be effective in performing those activities. Helix calls these **proficiencies**.

By coding all of these responses individually and then aggregating like responses, the Helix team has identified the key proficiencies of systems engineers. These are elaborated in (Pyster et al. 2015). In brief, there are six proficiency areas, each of which contains several related groups of skills, or **categories**, as described below:

1. **Math/Science/General Engineering:** Foundational concepts from mathematics, physical sciences, and general engineering. Categories include: Natural Science Foundations; Engineering Fundamentals; Probability and Statistics; Calculus & Analytical Geometry; and Computing Fundamentals.

2. **System's Domain & Operational Context:** Relevant domains, disciplines, and technologies for a given system and its operation. Categories include: relevant domains, relevant technologies and systems; relevant disciplines; familiarity with the system's concept of operations.

3. **Systems Engineering Discipline:** Foundation of systems science and systems engineering knowledge. Categories include: lifecycle; systems engineering management; systems engineering methods, processes, and tools; and system complexity.

4. **Systems Engineering Mindset:** Skills, behaviors, and cognition associated with being a systems engineer. Categories include: big-picture thinking; paradoxical mindset; flexible comfort zone; abstraction; and foresight and vision.

5. **Interpersonal Skills:** Skills and behaviors associated with the ability to work effectively in a team environment and to coordinate across the problem domain and solution domain. Categories include: communication; listening and comprehension; working in a team; influence, persuasion, and negotiation; and building a social network.

6. **Technical Leadership:** Skills and behaviors associated with the ability to guide a diverse team of experts toward a specific technical goal. Categories include: building and orchestrating a diverse team; balanced decision making and rational risk taking; managing stakeholders and their needs; conflict resolution and barrier breaking; and business and project management skills.

In addition, the non-systems engineers in the sample – project managers, classic engineers, executive leadership, and human resources personnel (HR) – were asked which proficiencies they considered critical in the most effective systems engineers with whom they worked. These were also coded and aggregated with the systems engineers' responses; they validated the existing categories.

In 2015, the Helix team provided the and reviewed the draft proficiency model to participants and had them react to the categories and structure directly. The existing structure was validated, with no additional skills being cited that did not fit within existing categories; this did, however, help the team in re-allocating some proficiencies to other categories to make them more easily understood by a wider audience.

Finally, systems engineers were asked to perform self-assessments of their own proficiencies at different points in their careers, which could then be overlaid with their career paths. Early on, the Helix team would perform its own assessments during these discussions and map them against the self-assessments to ensure alignment between the team's approach and the participants'. They were also asked to cite what they believed were the most critical proficiencies for their *current* positions. In addition, some were asked to identify what they believed were the minimum proficiencies to be effective in their current positions. Non-systems engineers also did self-assessments, to help identify where these proficiencies overlap with other disciplines. In addition, they were asked what they believed were the most critical proficiencies or the minimum proficiency level they would desire in the systems engineers that they work with. All of this work helped to validate the proficiency set as a useful and comprehensive model.

The forces identified in Figure 1 – experiences, mentoring, education and training – are linked to the growth of proficiency by interview data. When an individual would cite a critical skill, the Helix team would ask how that individual had developed that skill over time. These types of discussions were cross-coded for both the relevant force(s) and the related proficiency(ies).

2.5.5 Mapping a Career Timeline

As described above, chronological time is an attribute of all positions. The final step in developing a career path map for an individual was to create a visualization over time of all of the elements listed above. This visualization lays out all of an individual's positions, and their characteristics over time, with their education, the career milestones, and their proficiency assessments. Figure 4, below, shows a generic example of this.

In Figure 4, only the timing, roles and the lifecycle stages characteristics of positions are illustrated. This is for two reasons: one is ease of visualization in a single graphic – though any combination of attributes is possible in this format – and the second is that systems engineers were able to provide the clearest discussions on how *roles* and *lifecycle* exposure contribute to proficiency. For other attributes, these relationships were more sporadically represented in the data; in addition, not all systems engineers provided basic data on all attributes, but the Helix team was able to complete roles and lifecycle data for nearly the entire dataset (93% for roles; 91% for lifecycles).

By creating these individuals "maps" for each career path, it is possible to start identifying patterns – not only in proficiencies but in the common attributes that lead to similar proficiency profiles. Additional analysis of the career paths of individuals in similar roles was also insightful; even though there is some individuality to each systems engineer's career, the common patterns indicate ways that systems engineers may typically grow – or areas where certain types of systems engineers differ from others. The analysis highlighted in this paper is that of chief systems engineers – not only of their career paths overall, but in a few critical cases, highlighting their differences from other senior systems engineers.

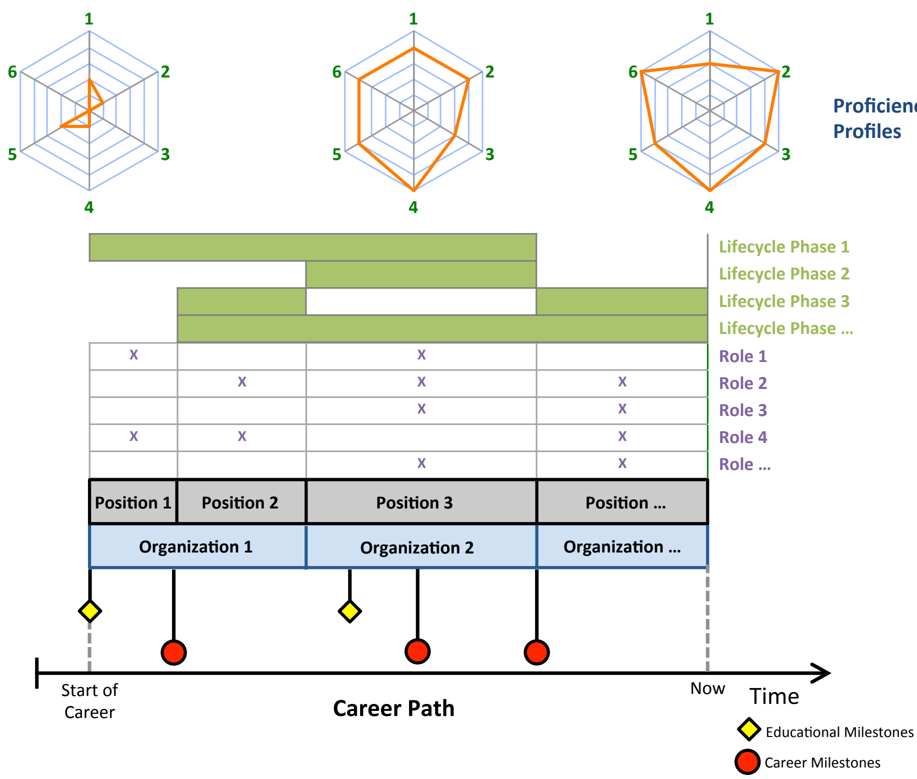

Figure 4. Generic Career Path Mapping

2.5.6 Steps to Validate Findings from Career Paths

There were several ways in which the findings from career paths were verified and validated. The most straightforward was verification through follow-up interviews, where individuals were presented with the current analysis of their career paths and asked to provide any corrections or fill any gaps. Though only 48% of interviewees also participated in follow-up interviews, the changes and updates were minimal, and often reflected additions where certain aspects of an individual's career had not been discussed in the initial interviews. Because the reviews by individuals of their own career paths revealed no major issues with the methods, the Helix team considered that the method is a valid approach to understanding the causes of change and growth over time.

In terms of additional validation, the Helix team acknowledges that, for a number of reasons, the way an individual progressed through her career may not have been an optimal approach. Participants were asked to identify areas where what they would have approached their careers differently based on their current levels of insight. They were also asked their general satisfaction with their career progression and to identify areas where colleagues might have had a different, preferred approach. And because – as explained in the dataset discussion above – the interviewees identified themselves and their organizations identified them as all of "average" to "excellent" effectiveness, it is reasonable to draw conclusions about the career paths of these individuals.

Finally, in 2015, the Helix team worked with one organization to pilot the career path approach. Individuals worked through an example career path with the Helix team and then mapped their own careers in real time. The feedback was that this approach was much better structured and focused than any career guidance they had received. In some cases, this reinforced that their current planning was appropriate, and other individuals reported that with insights from their career paths, they realized that they needed to seek new opportunities. All of the participants (n=34) agreed that this approach was useful and would be a valuable tool for them as individual systems engineers and for the organization.

2.6 Capstone on Proficiency and Career Paths

In 2017, the Helix team worked with a student at the Stevens Institute of Technology, Matthew Partacz. Mr. Partacz joined the Helix team as a student and his capstone project utilized historical Helix data and Helix methodologies, along with additional approaches, to examine the relationship between career paths, proficiency, and project or program performance. One hypothesis of Mr. Partacz's study was that career path has a quantifiable impact on an individual's systems engineering (SE) proficiency. The following is an excerpt from Mr. Partacz's *Capstone Report* (2017), which captures the strong correlation he found between experiences and proficiency.

There are many different ways to look at career path, but for this study career path was looked at very broadly. Career path was assessed by classifying each individual in the HELIX dataset into one of three categories as shown in Table 1.

Table 1: General Career Path Classification Definition

	New Engineer	Experienced, Never Titled Systems Engineer	Experienced Titled Systems Engineer
Years of Experience	Less than 9 years	Equal to or greater than 9 years	Equal to or greater than 9 years
Positions Title's	-	0 years titled as Systems Engineer	Greater than 0 years titled as Systems Engineer

SE proficiency, as defined in Atlas, consists of six different areas based on HELIX interview data. Many individuals in the HELIX dataset completed a self-assessment, rating how they believe they perform each SE proficiency at the time of the assessment. The six different areas are defined in Table 2.

Table 2: Atlas Proficiency Area Definitions

Area	Definition
Math/Science/General Engineering	Foundational concepts from mathematics, physical sciences, and general engineering.
System's Domain& Operational Context	Relevant domains, disciplines, and technologies for a given system and its operation.
Systems Engineering Discipline	Foundation of systems science and systems engineering knowledge.
Systems Engineering Mindset	Skills, behaviors, and cognition associated with being a systems engineer.
Interpersonal Skills	Skills and behaviors associated with the ability to work effectively in a team environment and to coordinate across the problem domain and solution domain.
Technical Leadership	Skills and behaviors associated with the ability to guide a diverse team of experts toward a specific technical goal.

With each general career path classification and proficiency self-assessment we can begin identifying relationships between the two. Relationships are evaluated and presented in two ways: (1) via mosaic charts and (2) using non-parametric statistical analysis, similarly to The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey 0, Section 4.2.

When creating mosaic charts, the only difference to The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey 0, Section 4.2.1 is that career path classification definitions were *arbitrarily chosen instead of divided using the weighted summed indices. It is also important to note that the weighted summed indices were determined using the cumulative score for SE proficiency and not for each individual area of SE proficiency.*

Non-parametric statistical analysis was conducted just as in The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey 0, Section 4.2.2. Goodman and Kruskal's Gamma and p-value is a measure of association which expresses the strength of the relationship between two ordinal variables. Notionally, Gamma values may be interpreted as:

$$0.0 \leq |Gamma| < 0.2 \rightarrow Weak\ relationship$$
$$0.2 \leq |Gamma| < 0.3 \rightarrow Moderate\ relationship$$
$$0.3 \leq |Gamma| < 0.4 \rightarrow Strong\ relationship$$
$$0.4 \leq |Gamma| \rightarrow Very\ strong\ relationship$$

Important to note, p-values are always cited with each Gamma statistic. P-values are typically used for rejecting the null hypothesis; the lower the p-value the less likely the magnitude of the relationship is to be a chance occurrence. It is conventional that values of p<0.05 or p<0.01 be used as a basis for rejecting the null hypothesis.

For full details on Mr. Partacz's capstone project, see his full report (2017). With Mr. Partacz's help in data collection and analysis, the Helix team was able to cross-reference career paths generated for many of the systems engineers in the sample with their proficiency self-assessments, a critical step in further validating importance of the career path assessment approach and providing more insights on how career path patterns align with proficiency. This work is reported in the *Career Path Guidebook.*

2.7 Helix Data

Helix research uses a bottom-up approach, based on the data being analyzed. Hence, it is essential to gather data that is sufficient in quantity and quality to enable effective development of *Atlas*, and to provide reliable insights and recommendations that can be confidently used for the development of effective systems engineers.

2.7.1 Data Sources

The primary source of data for Helix research is face-to-face semi-structured interviews with participants at their place of work. Additional information about the participant and the organization were also collected as available. Another data source that Helix gained access to was the application data for the INCOSE Systems Engineering Professional (SEP) certification program.

2.7.1.1 Helix Interview Data

From June 2013, when Helix conducted its first site visit for data collection, until January 2018, a total of 363 participants were interviewed from 22 organizations. Typically, 2 to 3 members of the Helix team interviewed anywhere from 1 to 6 participants in a single interview session.

Interview participants, if willing, also provided their resumes with details about their educational background, work experiences, and any other information they wished to provide.

Follow-up interviews were conducted over telephone with willing participants, to explore topics that could not be covered in the initial face-to-face interviews or to collect additional information based on their resumes. Follow-up interviews were also used to validate results of Helix analysis.

In both the initial interviews as well as follow-up interviews, transcripts were created when audio recording was permitted; when not permitted, summaries were prepared from notes taken during the interviews. These transcripts and summaries from a total of about 270 hours of interviews form the bulk of data that Helix analyzed.

2.7.1.2 INCOSE SEP Application Data

INCOSE provides three different levels of SEP certification: Associate (ASEP), Certified (CSEP), and Expert (ESEP). Applicants from all over the world seeking INCOSE certification apply for the appropriate level based on their systems engineering experiences, knowledge, and accomplishment. INCOSE provided to Helix, under a Non-Disclosure Agreement, over 3000 application forms received from applicants during the period May 2004 to May 2014. Though the application data was available in electronic form, it was not in a format that would readily support analysis. Significant time and effort was spent in extraction, cleaning, and tabulating the data to enable further analysis.

Analysis of INCOSE data did not directly contribute to the building of *Atlas*, but provided some validation and additional insights for the analysis of the interview data.

2.7.2 Demographics

2.7.2.1 Demographics of Sample Population

Understanding the sample population is important, since the interview data is reflective of the population from which it has been collected, and in turn, that data is the basis for *Atlas*. An understanding of the INCOSE applicants reveals the breadth of the data that it contains.

2.7.2.2 Demographics of Helix Dataset

Understanding the sample population is important, since the interview data is reflective of the population from which it has been collected, and in turn, that data is the basis for identifying career paths. Following the rubric for understanding the seniority of systems engineers presented in Figure 5, the results are presented in Figure 5. Senior participants cover almost two-thirds of the population while the remaining one-third is almost split almost evenly between junior and mid-Level participants.

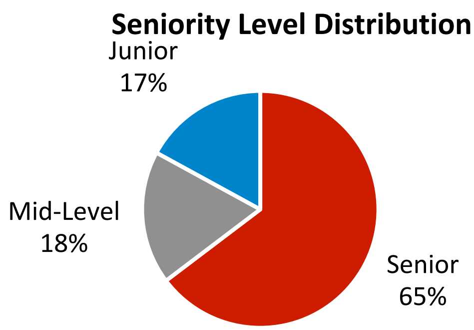

Figure 5. Distribution of seniority levels across Helix dataset

Figure 6 illustrates the distribution of participants based on the "general career path classifications" used in Partacz (2017). It divides the sample by individuals who are recognized – and recognize themselves as systems engineers – and those who do not. A third category "new engineer" denotes any individual with less than nine years of experience. Note that this is different than the Helix seniority classifications, which do not depend on time.

It can be observed that more than two-thirds of Helix participants are Experienced Systems Engineers. New Engineers are slightly behind Experienced Systems Engineers with only 31% of the participants being allocated to New Systems Engineers. On the other hand, an almost even distribution occurred among Experienced Systems Engineers who have never been officially titled "systems engineer" and those who have.

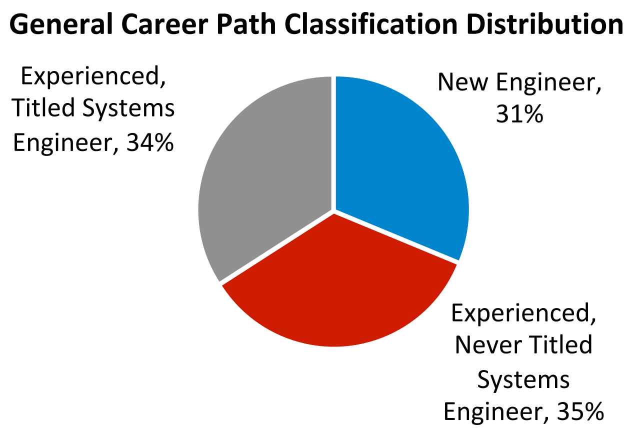

Figure 6. Distribution of career path classification across Helix dataset (from Partacz 2017)

Figure 7 denotes the distribution of gender across the Helix dataset. It can be observed that more than three-fourths of participants are male systems engineers. In each organization, the Helix team requested additional information on the overarching systems engineering workforce – as opposed to only the sampled individuals. Most organizations could not or chose not to provide this information. The Helix team does not know if the demographics of the sample reflect the overarching gender demographics of the populations or is a result of the way in which organizations selected individuals for participation.

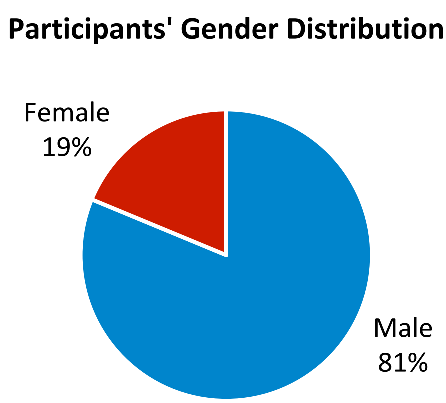

Figure 7. Distribution of genders across Helix dataset

To provide a more detailed context about Helix findings, it is helpful to understand the domain in which the systems engineers interviewed perform their activities. As it can be observed in Figure 8, from every four participants, three are related to Defense type of organizations. The rest of participants are involved in the domains of Healthcare, Transportation, Telecommunications, or Information Technology.

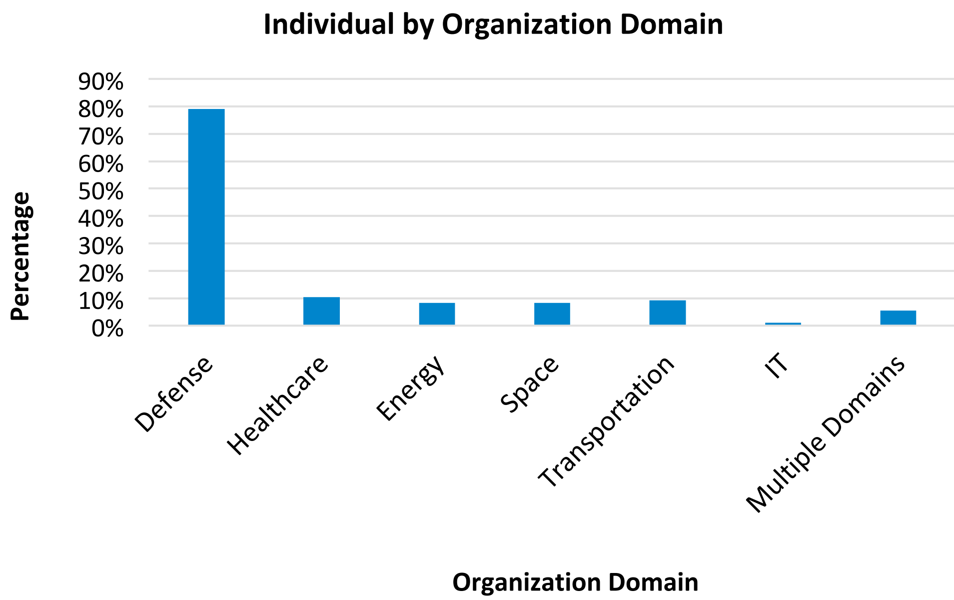

Figure 8. Distribution of Individuals by Organization Domain

Another classification of the type of participant organizations is their commercial affiliation. Helix classified commercial affiliation into: Government, Industry and Federally Funded Research and Development Centers (FFRDC). As it can be observed in Figure 9, more than half of the participants belong to industry organizations. The rest of the dataset is distributed among government entities and FFRDC, the former covering more than 20%, while direct government organizations slightly less than 20%.

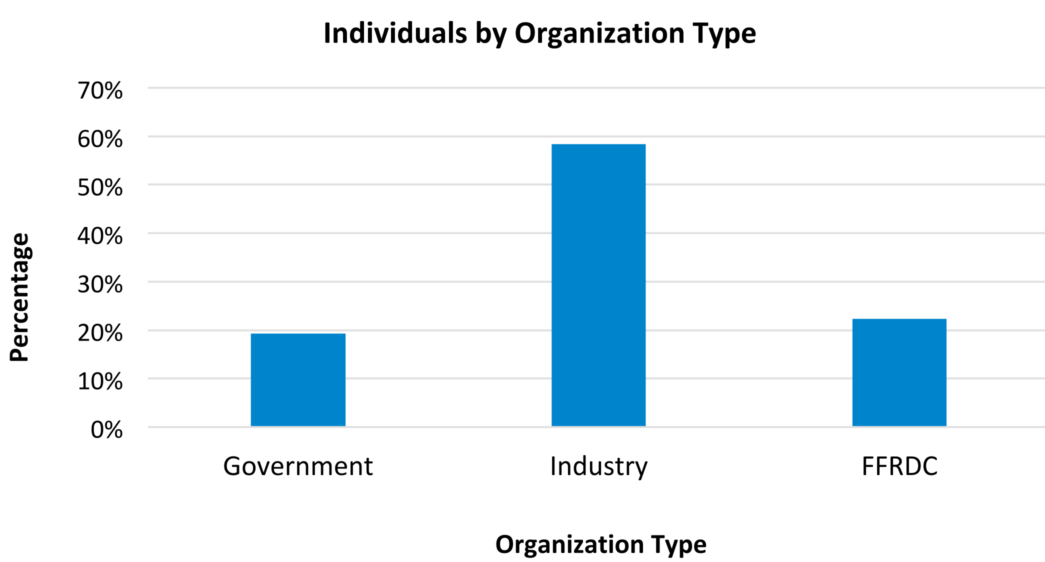

Figure 9. Individuals by Organization Type

2.7.2.3 Demographics of INCOSE SEP Applicants

From the over 3000 application forms, about 2500 unique applicants were identified for further analysis. These applicants were predominantly from the U.S, but there were others from Asia and Europe as well, as indicated in Table 3.

Table 3. Geographical Distribution of INCOSE SEP Applicants

Rank	Country	# Applicants	% Total
1	U.S.	1847	74%
2	India	179	7%
3	Germany	151	6%
4	France	101	4%
5	U.K.	49	2%
6	Sweden	41	<2%
7	Spain	36	1%
	Other	100	4%

Information from all the 2504 unique applicants was used for analysis of education background; a subset of those applicants was analyzed for experiences.

2.8 Interpretation and Generalization Using the Dataset

Helix is careful when using the data to understand whether and how findings and conclusions about the dataset can be generalized to the wider population of systems engineers. The team recognizes that there are some limitations based on the sample. Though it is relatively large at nearly 300 individuals, there is no clear estimate of how many systems engineers are working in the US, let alone the world; this makes it difficult to understand how statistically representative the sample may be. Likewise, all interviews conducted to date have been in the US; though a few individuals provided insight into, for example, education outside the US, and some organizations had units outside the US, current findings reflect a US context. Likewise, though Helix has expanded beyond its initial defense roots to include healthcare, transportation, telecommunications, and other industries, Figure 3 clearly shows that the majority of individuals participating in the sample are from the defense industry. Given these limitations, the Helix team is careful not to over-interpret the data.

However, even with the limitations of the sample, the team believes the overall size of the sample and the diversity in terms of industries, organization types, and seniority makes any findings and conclusions drawn from the data extremely useful, even if they are not fully generalizable. The Helix team first published *Atlas* 0.25 in 2014; since then the coverage of industries and organizations has grown and the team has nearly doubled the size of the sample. And over this time, there have been some updates and edits, but no major issues or breaks with the theory have been discovered. This, again, builds confidence that the existing sample is sufficient to enable useful and insightful work. As the team continues work on implementation and application of *Atlas* (see Future Directions), these activities should generate greater confidence in the generalizability of the data.

3 HELIX ACTIVITIES IN 2017

This section provides a brief overview of the work of the Helix team in 2017. As cited below, the primary results of the study are found in companion documents.

3.1 WORK FOCUSED ON EFFECTIVE SYSTEMS ENGINEERS

The Helix team completed conducted three site visits in 2017, adding three organizations and 76 additional individuals to the dataset (see section 2.7 for a description of the updated dataset). In addition, the team performed additional analyses to create three new documents for the Helix library:

- **Atlas *1.1: The Theory of Effective Systems Engineers*** – (SERC-2018-TR-101-A) This is an incremental evolution of *Atlas* that reflects feedback from the community, additional analysis, and maturation of the team's thinking in 2017. In particular, *Atlas* includes minor updates on the values systems engineers provide, the roles systems engineers play, the proficiency model for systems engineers, and the personal characteristics of systems engineers. Henceforth, this will be referred to as "*Atlas* 1.1".

- **Atlas *Career Path Guidebook*** – (SERC-2018-TR-101-B) This document provides analyses of the Helix dataset, providing common patterns in systems engineers' careers. The Guidebook also provides some insights on questions commonly asked of the Helix team around career paths and the team's responses. Finally, additional work on linking proficiencies to career paths has been completed and is reflected in the guide. Henceforth, this will be referred to as the "*Guidebook*".

- **Atlas *1.1. Implementation Guide: Moving from Theory Into Practice*** – (SERC-2018-TR-101-C) Whenever *Atlas* is presented, there are many questions about how to take the theory and apply it in practice. The Guide provides examples from organizations that have implemented parts of *Atlas*, and guidance created by the Helix team based on many interactions with organizations around implementation as well as the extensive Helix dataset. Henceforth, this will be referred to as the "*Implementation Guide*".

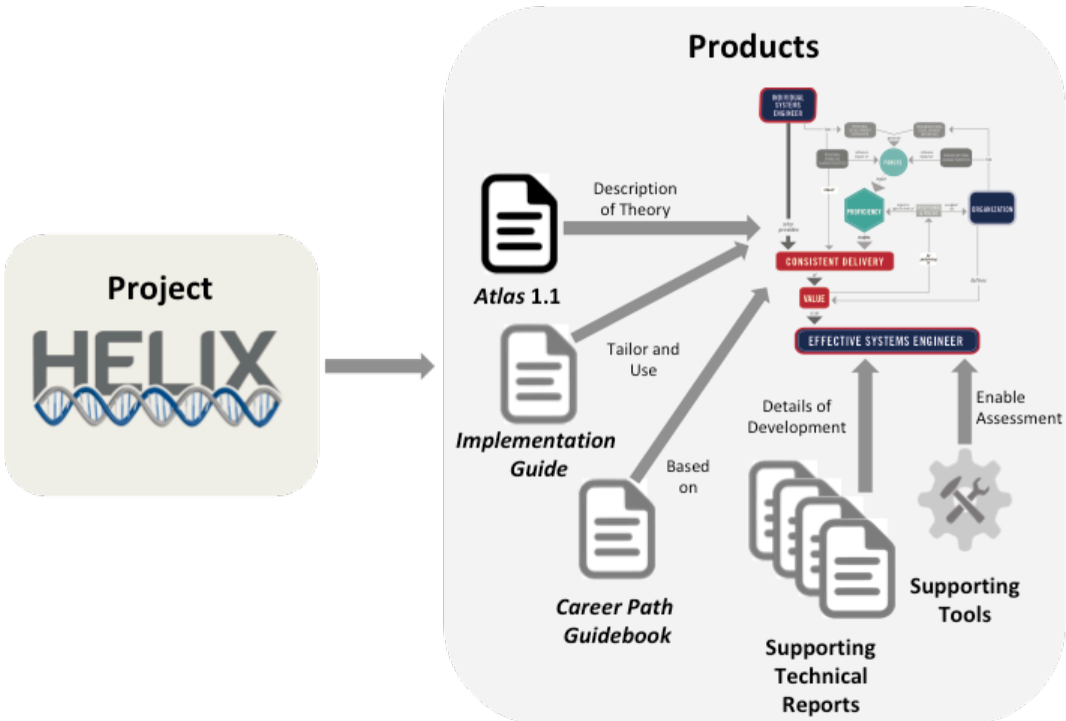

Figure 10. Relationship between "Helix" and "*Atlas*"

The relationships between these documents are highlighted in Figure 10, above.

In 2017, the Helix team conducted additional work on effective systems engineering capabilities, culminating in *Atlas* 1.1, which is an incremental update reflecting additional analysis of existing data as well as additional data collection in 2018. Though the changes in *Atlas 1.1* are relatively minor (as reflected in the ".1" version number), they nevertheless reflect not only additional data collection and analyses, but also incorporate feedback from the community. The Helix team presented their work at several community events, including the IISE annual conference, the INCOSE International Symposium, the NDIA Systems Engineering Conference, and the SERC Sponsored Research Review (SSRR). At each of these events, the team gained feedback from the community, collecting frequently asked questions, uncovering areas of confusion, and identifying areas for improvement. The changes include:

- Revision of the *Atlas 1.1* graphic that explains all of the key variables included in the theory. The content did not change, but the team believes the update better highlights the two critical actors – individuals and organizations.
- Reordering of the values systems engineers provide to reflect the frequency at which they occurred in the dataset.
- Updating the "Requirements Owner" and "Systems Architect" roles. The activities around functional architecture were moved from Requirements Owner to Systems Architect which both better reflect the realities of the grouping of these activities in

practice, but are groupings which better align with the mental models of most individuals who have engaged with the Helix team in 2017.

- There were several minor edits to the proficiency model. The proficiency areas stayed the same, though the area formerly titled “Systems Engineering Mindset” is now “Systems Mindset”. Within this area, the category formerly titled “flexibility” has been renamed “adaptability”. This not only better reflects the comments in the Helix interviews – which revolved around the ability of an individual to cope with a change – but also reduces confusion. The distinction between proficiencies and personal enabling characteristics is nuanced, and the term “flexibility” caused confusion about the classification of the category. In addition, the titles of categories in the “Technical Leadership” proficiency area were updated to increase clarity. The previous titles implied overlap; e.g. “Managing Stakeholders with Diverse and Conflicting Needs” and “Conflict Resolution and Barrier Breaking” seemed to overlap, though their topics were different. Though they are related, they are distinct. The Helix team renamed “Managing Stakeholder with Diverse and Conflicting Needs” to “Managing Diverse Stakeholders”.

- There were minor edits to personal characteristics, particularly the update of definitions for “inquisitiveness” and “life-long learning” to help clarify the distinction between the two.

In addition to the work on *Atlas 1.1*, the Helix team continued the work of Dr. Hutchison, building on her dissertation dataset on career paths by creating career paths for additional individuals in the sample as well as collecting new career path data. As *Atlas* was refined, the team updated the analyses around career paths to reflect these changes. The career path data was then reanalyzed for patterns. The results of these analyses can be found in the *Career Path Guidebook*.

In addition to these analyses, the *Guidebook* contains insights from the team on how to interpret and apply some of this guidance. A series of frequently asked questions – and the team’s answer to these questions – is incorporated into the guidebook.

Finally, Mr. Matthew Partacz based his capstone project for his master’s in systems engieneering at Stevens on the Helix project. Mr. Partacz examined the relationship between career paths and proficiency and looked for a link between these and project performance. Mr. Partacz’s report can be found on the Helix webpage (sercuarc.org/projects/helix) but key findings related to career path are summarized in the *Guidebook*.

3.1.1 ADDITIONAL ANALYSIS OF PROCESS DATA

In 2017, the Helix team examined the existing data to understand how the data could support this broader scope. The summary of that work is that the Helix team has some information on

Structure, though it varies widely between organizations, little on governance as most participating organizations chose not to share their policies around systems engineering – or simply did not have such policies. There is very little information on the dataset on process. As the team was focused on individual systems engineers, process was not the focus. In the little data available, there are three findings:

- Process can be important, but is not a substitute for experience. Overall, systems engineers who bring experience, insight, and foresight are valued. Systems engineers who only follow a process are not.

- Inexperienced systems engineers tend to lean very heavily on process and documentation, which can cause program mangers or peers to question the values they provide.

- Individuals at most organizations in the sample reported that their employers reacted to issues or failures by adding to their processes. Most of these individuals complained about the "bloat" in their processes as well as the lack of clear guidance on or authority to tailor the processes.

The above are not likely to be surprising to most people who have worked in or around systems engineering. The Helix dataset to date primarily consists of these types of qualitative assessments, which are useful but do not contribute to the same type of analyses as were conducted on, for example, proficiencies. The only additional data are the specific process an organization might follow, such as DoD 5000.02. Going forward, the Helix team needs to gather additional data around the processes used in organizations and how they impact the organization's ability to successfully develop, maintain, or update systems.

The approaches the Helix team plans to use to address these issues around process in 2018 are discussed in Section 4, below.

3.1.2 Additional Analysis of Organizational Data

In order to mine the data for relevant attributes around organizational data, the team identified and defined seven primary characteristics of organizational cultures based on work by Schein, (2010); Cameron and Quinn, (2011), and the PMBOK guide definitions of organization structure. See Appendix C for detailed definitions of the seven characteristics.

1. **Status** afforded Systems Engineers (High, Low, In Transition)
2. **Structure** (SE is Functionally Centralized vs. Distributed – Strong, Balanced, or Weak Matrix, Function, Project)
3. **Professionalism** (High, Low, In Transition)
4. **Formality** (High, Low)
5. **Influence** (High, Low)

6. **Collaboration** (High, Low: Strength, Breadth)
7. **Change** (types: planned, dynamic; SE involvement)

First, the team selected four transcripts from four different organizations to code for the seven characteristics to a) determine how easy or difficult it would be to apply the rubric and b) get a first indication of the presence or absence of interpretable data in the existing data set. From this analysis it was determined that a) it was possible to reliably code for the seven characteristics across two coders, and b) in these transcripts, some culture indicators were present while others were not. In particular, SE status, structure, professionalism and formality were observed to some degree, while there were no clear indicators of influence, collaboration and SE involvement in organization change present in this subsample.

Second, the team expanded the test of the usefulness of mining existing data by coding the seven characteristics in all transcripts for one organization. By examining 325 pages of transcripts from 33 interviews from one organization, 57 pages were extracted that contained some reference to one or more culture characteristics.

Conclusions from these additional analyses of organization data include:

- The interviews contain some relevant data on organization characteristics, though for several characteristics the data is sparse.
- Where it is possible to code for specific characteristics, it is difficult to interpret the meaning of the presence or absence of specific characteristics without discussion since the impact of culture characteristics depends on how members of the culture interpret them. Meaning, relevance, and impact must be determined in context by the participants in the culture.
- These analyses enabled the team to identify specific interview probes that can elicit more meaningful data in future interviews. These probes were further tested in the three additional site visits subsequently performed in 2017.

Testing the Meaning and Value of the Organization Constructs

Based on the analyses of existing data and experience with the three new organizations interviewed in 2017, the Helix team refined the characteristics and added two additional areas of interests to test for relevance at the 4th Annual Helix Workshop in October 2017. (See Workshop Report, Hutchison et al. 2017) Participants individually completed an analysis of their own organizations based on the seven culture characteristics and questions related to (a) how the roles, status, and behaviors of the Non-SE talent areas (ME, EE, CS, etc.) affect SE growth and effectiveness in their organizations, and b) how the customer's (or customers') culture, values, and expectations of SE affect SE growth and effectiveness in their organizations.

The group discussion about the meaning, importance and applicability of the chosen cultural attributes to their organizations revealed that the attributes are meaningful and important and that the presence and impact of the attributes varies greatly across organizations. Participants encouraged the team to continue to explore these aspects of organization capability and their impact on SE growth and effectiveness. The workshop validated that organizations can increase their awareness about the impact of their own organization cultures on SE by using a simple and relevant lens through which to observe their culture and behavior.

Overall, the work in 2017 increases the team's confidence that:

1. Tools for observing and describing attributes of organization culture, structure and governance can increase awareness and options for growth within an individual organization.

2. Describing the variability and inter-relationships of various culture, governance, and structure attributes across organizations and their impact on Systems Engineering capabilities can advance our understanding and development of the Systems Engineering profession.

3.1.3 Additional Analysis of Methods and Tools Data

The Helix team reviewed the information in the current dataset around systems engineering methods and the tooling to support systems engineering. A list of the most common tools mentioned in the dataset can be found in Table 4.

Table 4. Cited Tools and Methods from the Helix Dataset

Most Commonly Cited (>50% of Interviews)	Occassionally Cited (10% < x < 50%)	Rarely Cited (<10% of interviews)
Rational Rhapsody DOORS	MagicDraw	MBSE Matlab Risk Radar Team Center MKS PLM 3D CADX Microsoft Project Microsoft PowerPoint Microsoft Excel SysML Artisan Studio Risk Recon SEER Vitech Core Red Mine O-NET

In addition to examining the methods and tools in the dataset, the Helix team also reviewed how individuals discussed these tools in their interviews. Because this was not a major focus, the data is sparse, but the following are common patterns seen to date:

- Individuals in almost every organization described tooling as an issue or challenge.
- In some organizations, the individuals felt that the organization had either not yet identified sufficient tools or did not believe in investing in tools specific to systems engineering.
- In others, the tools had been identified and were in use in the organization, but individuals did not have access to them. This was often because there were not enough licenses for the number of individuals who believed the tools would be useful in their work or because those tools were only utilized in some areas of the organization.
- Modeling was a common point of discussion, particularly in terms of how it could be transformational to the systems engineering work. Different terms were used to describe this (model-based systems engineering, model-oriented systems engineering, model-based engineering, etc.), but individuals were excited about the possibility of using models to help guide the work and capture the results, rather than the document-based approach that primarily dominated the landscape.
    - Some organizations reported having a model-based systems engineering initiative. The individuals in the organization were all excited about this but expressed that they did not believe the modeling and tools were sufficiently mature to support this yet. In some organization, individuals reported that the tools "worked well enough" but that the alignment between the model-based approach and the organization's process meant that significant level of effort was still required to produce the expected document-based artifacts. So while the approach was seen as beneficial, it was also considered a major burden to the programs.
    - In one organization, an entire program was developed using the model-based approach. The benefits of this approach were widely recognized within the organization, and many individuals reported a desire to do this approach on their own programs. However, the shift to a model-based approach in this organization included having several individuals dedicated specifically to modeling, which significantly added to costs. The organization and individuals wanted this to broaden, but the funding challenge associated with this has to be resolved.

The above represents the current state of the data in *Atlas*. Future work will include examining this as part of the "infrastructure" of the organization, which will be described further in Section 4.

3.1.4 Additional Data Collection

In 2017, the Helix team added 76 new individuals and 3 new organizations to the dataset. This bring the dataset to a total of 363 participants were interviewed from 23 organizations.

During the year 2017, data from 3 new organizations was added into the Helix dataset. The dataset saw an increment of 76 new inputs that were analyzed aggregately to identify career paths in systems engineering.

Figure 11 illustrates the comparison of seniority levels among Helix participants. As it can be observed, the input data is consistent with precious pattern. Before the year 2017, the demographics were the following: junior (19%), mid-level (15%) and senior (66%). Once the information of new participants was included, the percentage of junior systems engineers decrease to (17%). Mid-level increased 2% to a total of 17%. There was no observed change with respect to the percentage of senior systems engineers, both classifications reported the total demographics of systems engineers to be 66%.

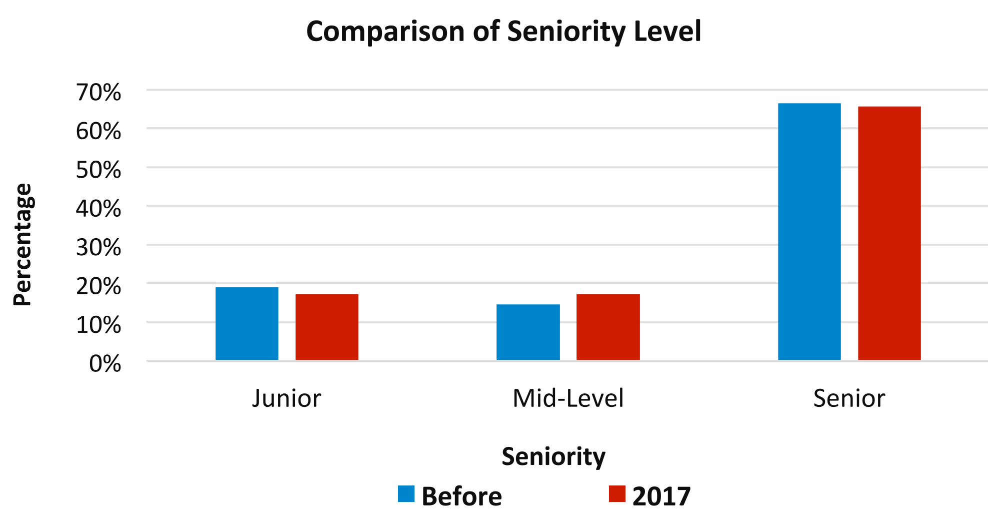

Figure 11. Comparison of seniority level distribution

In regard to the types of organization the Helix team has collaborated, Figure 12 denotes the comparison among previous analyzed data against the new organizations included during 2017. Federally Funded Research and Development Centers (FFRDC) type of organization double in percentage during the 2017. Industry type of organizations decreased from 65% to 58% after the including the new data. Lastly, government entities were consistent with previous years data.

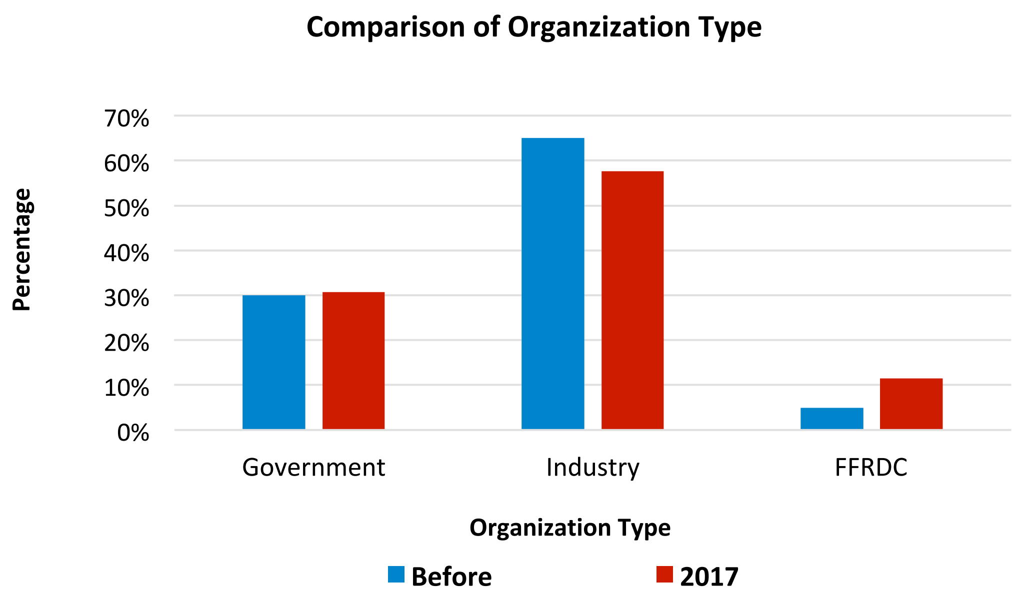

Figure 12. Comparison of organization type distribution

3.2 Updates to the Research Questions

From 2012 through 2016, the Helix team focused on three primary research questions. They were:

1. What are the characteristics of systems engineers?
2. What makes systems engineers effective and why?
3. How can organizations improve the effectiveness of their systems engineers?

With the publication of *Atlas* 1.0 in December 2016, the Helix team believed that questions 1 and 2 were answered reasonably well; they could be improved upon, but the foundations of *Atlas* had remained largely stable for over a year and additional data collected reinforced rather than contradicted the findings.

Despite the progress made to date, additional work was required to ensure that Helix and *Atlas* fulfilled their potential impact with the community. For example, *Atlas* provides great insight for individual systems engineers, but is it possible to understand the effectiveness of systems engineers in teams or a collective systems engineering workforce. The Helix team received frequent questions from the community not only about how to implement *Atlas* but whether Helix would also address the "next level" - the broader context around the systems engineering capabilities supported by the systems engineers in an organization.

With this in mind, in 2017, the research team updated the research questions to reflect this shift in focus. The research questions became:

1. **How can organizations improve the effectiveness of their systems engineering workforce?** This question has two areas of consideration: first, how can the effectiveness of the workforce itself be understood? Is it simply a collection of individuals or are there synergies when looking across the workforce as a whole? The Helix team has worked with several organizations to understand how they can utilize *Atlas* in practice and to date, each of them treats their workforce as a collective of individuals, not as a holistic entity. There is additional research required to better understand whether this is accurate or whether in systems thinking parlance, "the whole is truly greater than the sum of its parts". This will provide important insights as organizations look to how to grow their workforce, not just individual members of it.

   This leads to the second part of the question, which is how can organizations actually make an impact in this area? In 2017, the Helix team collected additional data on organizational initiatives, all of which aligned with previous findings in *Atlas* 1.0.

2. **How does the effectiveness of the systems engineering workforce impact the overall systems engineering capability of an organization?** The unspoken hypothesis here is that having an effective systems engineering workforce should result in effective systems engineering capabilities. However, there are many factors which impact a systems engineering capability and while the Helix team anticipates that the systems engineering workforce plays a critical role, as with the *Atlas* theory, the team also anticipates that several other factors will impact the ability of even a very skilled workforce to translate skill into effective action. In order to understand this, the team has to answer the third question:

3. **What critical factors, in additional to workforce effectiveness, are required to enable systems engineering capability?** Based on the Helix work through 2016, the team developed an expected set of variables that would impact systems engineering capability, as illustrated in Figure 13.

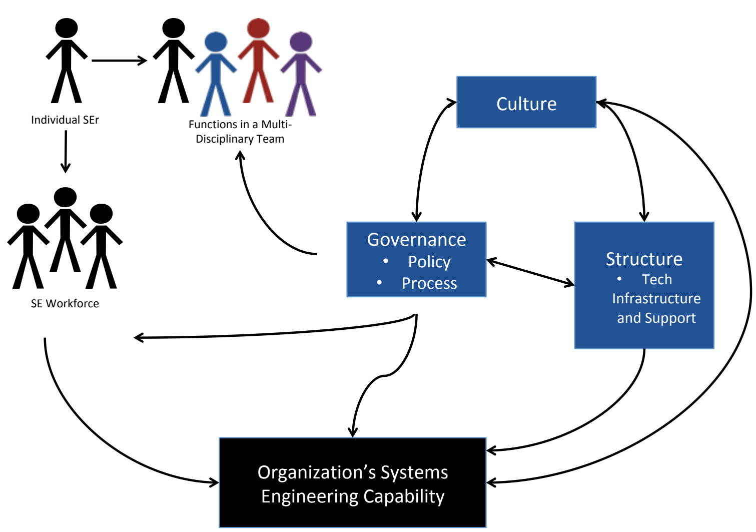

Figure 13. Expected Variables to Impact Systems Engineering Capability

The Helix team investigated potential uses of the existing interview data to address the expanded goal of understanding aspects of organizations that support effective systems engineering capabilities. Although the interviews were primarily focused on the individual, it was recognized that many interviewees referred to aspects of organization culture, structure, and governance when describing their own growth and effectiveness as systems engineers.

3.3 Related Work

This section highlights additional work done on *Helix* in 2017, specifically work by the SERC on a Helix tool and a book written by Art Pyster, Nicole Hutchison, and Deva Henry:

- The SERC believes that Helix and *Atlas* provide critical insights for individuals who wish to understand their systems engineering proficiencies, their career paths, and how the two link together. In 2016, the Helix team published an Excel template to facilitate self-assessments of both proficiency and career path, as well as paper-based tools. However, for wide-scale use of *Atlas*, the SERC believed that a web-based tool would be more critical. The SERC invested resources in 2017 to build a tool to support self-assessment. At the time of this report, the first iteration of the tool is nearly complete and will provide the following capabilities:

    - Individual proficiency self-assessments, allowing multiple assessments covering many points in time, including prompting users to create a "target" proficiency profile, and enabling tailoring of the proficiency model to fir the individual's working environment;

    - Proficiency graphics to allow individuals to easily compare proficiencies over time, and

    - Individual career path self-assessments, enabling data collection and characterization on the critical variables of career paths identified in *Atlas*.

    Future iterations are planned to enable visualizations of career paths over time as well as options for organizations, which would enable them to create an organization-specific tailoring of the proficiency model and collect data across their systems engineering workforce.

- In 2017, Art Pyster, the former PI for the Helix project, Nicole Hutchison, the current PI for the project, and Deva Henry, a researcher who worked on the project almost continuously for years, developed a proposal for a book based around the Helix findings. This book, which heavily references the published Helix reports, also provides the insights and opinions of the authors based on their long history with the research as well as additional on-the-record interviews, case studies, and views on the future of systems engineering and systems engineers.

This book will be submitted in January 2018 and it is anticipated that it will be published in late 2018.

4 Future Directions: Helix in 2018 and Beyond

As part of understanding what makes systems engineers effective, the Helix team has collected data on the ways that organizations try to improve their systems engineers' proficiency (called organizational development initiatives) and some basic trends have been identified. This area requires further study and is critical to ensure that organizations that identify issues in their systems engineering workforce or organizational support for systems engineering can understand the potential impact of and options for improvement.

Atlas 1.1 outlines what impedes and enables systems engineers, from aspects of the individuals themselves – such as proficiency, career path, roles, and positions – to aspects of the organization, such as culture and the specific ways that systems engineering is valued and promoted (or not). The information on this context for systems engineers in the current dataset is helpful, in particular in highlighting where these areas can inhibit systems engineers' effectiveness. However, the dataset is not as robust as is required in this area if organizations want to use *Atlas* to make real changes to improve their systems engineering workforce. Additional data must be collected on organizational culture, governance (including processes) and structure (including infrastructure and support for systems engineering).

The Helix team, in order to draw clear conclusions around the organizational characteristics, will need to greatly increase the organizational variability of the dataset. This will require a change in data collection approach. While some site visits with large numbers of individuals may still be necessary, the Helix team will also need to create a research protocol that will allow them to collect targeted organizational data with a lower level of effort to increase the number of participating organizations.

The Helix team, in order to better understand workforce versus individual effectiveness, must add new data on individual systems engineers and collect aggregate data on the systems engineering workforce from additional organizations. In addition, new analysis needs to be conducted to determine how to treat "the systems engineering workforce" as distinct from "individual systems engineers."

In 2017, the Systems Engineering Research Center developed tooling to support individual self-assessments based on the Atlas findings. The team needs to evolve the tooling to allow increased capability, including creating an option for organizations to tailor this for their own employees and see summaries of the results. This will aid the team in increasing collection of data that enables the aggregate analysis of individuals as a workforce.

The Helix team has begun exploring automated methods to glean additional insights from the existing dataset. The team needs to continue work on this in 2017 to reduce the burden of manual coding analysis on the more than 6,000 pages of text.

The Helix team will also conduct an extensive literature review of systems engineering capability and build on this work to develop clear methods for understanding and assessing how systems engineers are supported or impeded in providing an effective systems engineering capability.

In addition to the tasks above, the Helix team will begin building models to support this work. This will include modeling tools that will help enable organizations to assessment their current level of support for systems engineering and systems engineers. These models should eventually be able to help organizations explore the changes they could make to improve the efficacy of their systems engineering workforce and increase their systems engineering capability. (It is likely that this work will continue in 2019.)

As the researchers continue data collection and expand the variety of organizations participating, the team will gather additional data on the efficacy of organizational development initiatives that are intended to grow systems engineers.

The team shall develop a method for assessing the effectiveness of systems engineering capability in relation to the characteristics of the organization and the systems engineering workforce and validate this through data collection at a variety of organizations.

The researchers would aim to develop five items to support this work in 2018:

1) An initial framework for understanding the effectiveness of systems engineering (nominally *Atlas*^{ORG} 0.5);
2) A set of tools to support broader use by both individuals and organizations;
3) A series of draft models to support exploration of systems engineering capability with organizations; and
4) A technical report providing the data and analysis supporting each of the three items above.
5) Draft models developed to support the research.

4.1 Envisioned End State for Helix

The end goal for Helix, which will likely be completed in 2019, is to develop a theory of effective systems engineering capability – predicated on the hypothesis that *if an organization has a sufficiently skilled systems engineering workforce and the organizational characteristics such as culture, governance, and infrastructure align with systems engineering* – along with the tools to support organizations' self-assessment of their capabilities and their ability to change those capabilities. An appropriate analogy here is the "policy flight simulator", which according to Rouse is "designed for the purpose of exploring alternative management policies at levels ranging from individual organizations to national strategy." (2014) As Rouse explains, "the idea is for organizational leaders to be able to interactively explore alternative organizational designs computationally rather than physically. Such explorations allow rapid consideration of many alternatives, perhaps as a key step in developing a vision for transforming an enterprise."

By developing a theory of what enables an organization to have an effective systems engineering capability (e.g. Atlas^{ORG}), the Helix team will identify the key factors that impact this capability and the relationships between them. The founding hypothesis for this work will be, "*If an organization has an appropriately sized and skilled systems engineering workforce and the organizational characteristics are supportive of systems engineering, then the organization will have an effective systems engineering capability*."

With this theory and the rich dataset behind it, the team will be able to build tools to support data collection around critical variables, and models to support this policy flight simulator approach. With it, organizations can assess their current capability and the factors that influence it and run simulations to determine what organizational changes may enable an increased systems engineering capability.

Though process is anticipated to be one of the variables that Helix will study, this work is not intended to focus exclusively on making 'better processes'. There are already approaches for process improvement such as CMMI, SixSigma, and statistical process control. While there may not be many examples of these techniques applied to systems engineering processes, the Helix team nonetheless does not desire to create a process improvement methodology. Instead, areas of "process improvement" would include better aligning process with other variables in the model, such as culture, governance, or workforce capabilities.

5 Conclusion

The work on Helix in 2017 was critical preparation for the Helix work to come and has furthered the development of a community of interest in understanding and building exceptional systems engineers and systems engineering capabilities.

Accomplishments that provide a clear foundation for the next stages in this research include:

- The work performed mapping general theoretical constructs about organizational culture and governance to the systems engineering organizational context provides a starting point for designing future data collection, analysis strategies, and modeling approaches.

- By examining additional areas of the existing dataset, the team has a clear understanding of the status of the current data and where additional data collection is required.

- In updating the research methods and interview questions, testing these with three additional site visits, and reviewing the results, the team believes it has appropriate ways of asking for the required additional data.

The research process itself is developing a community of professionals who can influence the direction and effectiveness of systems engineering in diverse organizations in the future.

- By continuing the dialogue about systems engineering career paths, success stories, and applications of the prior research, and through the team's evolving understanding of critical culture and governance attributes, Helix is building a community of collaborators who are evolving the systems engineering profession in parallel with the Helix work.

- The methods the team uses to generate this dialogue include interview questions that spark self-awareness, site-visit summaries that provide organization leaders with new perspectives, cross-industry workshops, conference presentations, documents and references.

Ultimately, just as the growth and effectiveness of individual systems engineers depend upon the commitment of an organization to growing its systems engineering workforce capability, the value of the Helix work beyond supporting the development of individual systems engineers will be best realized through the engagement of our wider community of leaders of the systems engineering profession. The Helix team is committed to continuing this dialogue in 2018 and beyond.

WORKS CITED

Cameron, K. S. and Quinn, R. E. (2011). Diagnosing and changing organizational culture, 3rd Edition. San Francisco, CA: Jossey-Bass.

Davidz, H.L. 2006. *Enabling Systems thinking to Accelerate the Development of Senior Systems Engineers*. Dissertation, Doctor of Philosophy in Engineering Systems, Massachusetts Institute of Technology.

Elm, Joseph P., and Dennis R. Goldenson. The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey. Report no. CMU/SEI-2012-SR-009. Software Engineering Institute CERT Division, Carnegie Mellon University.

Firth, M. (1979). Impact of work experience on the validity of student evaluations of teaching effectiveness. *Journal of Educational Psychology, 71*(5), 726-730.

Ford, J. K., Smith, E. M., Sego, D. J., & Quinones, M. A. (1993). Impact of task experience and individual factors on training-emphasis ratings. *Journal of Applied Psychology, 78*(4), 583-590.

Kirschenbaum, S. (1992). Influence of experience on information-gathering strategies. *Journal of Applied Psychology, 77*(3), 343-352.

Kor, Y. Y. 2003. “Experience-Based Top Management Team Competence and

Partacz, M., N. Hutchison, D. Verma. 2017. Building a Better Business Case for Systems Engineering: The Relationship between a Systems Engineer’s Career Path, Proficiency and Project Performance. Hoboken, NJ: Stevens Institute of Technology.

PMI. 2013. A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 5th ed. Newtown Square, PA, USA: Project Management Institute (PMI).

Pyster, A., D.H. Olwell, T.L.J. Ferris, N. Hutchison, S. Enck, J.F. Anthony, D. Henry, and A. Squires (eds). 2015. *Graduate Reference Curriculum for Systems Engineering (GRCSE™)*, version 1.1. Hoboken, NJ, USA: The Trustees of the Stevens Institute of Technology ©2015. Available at: http://www.bkcase.org/grcse-10/

Rouse, W. 2014. “Human interaction with policy flight simulators.” *Applied Ergonomics*. 45(1): January 2014, pp. 72-77.

Schein, E. H.(2010). Organizational culture and leadership, 4th Edition. San Francisco, CA: Jossey-Bass.

Schmidt, F.L., J.E. Hunter, J. E., and A.N. Outerbridge. (1986). Impact of job experience and ability on job knowledge, work sample performance, and supervisory rating of job performance. *Journal of Applied Psychology, 71*(3), 432-439.

Sheard, S. 1996. “Twelve Systems Engineering Roles.” Proceedings of the International Council on Systems Engineering (INCOSE) Sixth Annual International Symposium, 7-11 July 1996, Boston, MA.

Sheard, S. 2000. "The 12 Systems Engineering Roles Revisited." Paper presented at the INCOSE Mid-Atlantic Regional Conference. April 2000. Reston, VA, USA. p 5.2-1 - 5.2-9.

Stuart, R.W. and P.A. Abetti. (1990). Impact of entrepreneurial and management experience on early performance. *Journal of Business Venturing, 5*(3), 151-162.

APPENDIX A: LIST OF HELIX PUBLICATIONS

Clifford, M. and N. Hutchison. 2017. “Helix: Understanding Systems Engineering Effectiveness through Modeling.” Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, 25 October 2017, Washington, DC.

Henry, D., Hutchison, N., Pyster, A., Dominick, P., Lipizzi, C., Kamil, M., Manchanda, S. “Summary of Findings from the Helix Project (2013-14) – An Investigation of the DNA of the Systems Engineering Workforce,” National Defense Industries Association Systems Engineering Conference, Springfield, VA, October 27-30, 2014

Henry, D., N. Hutchison, A. Pyster, P. Dominick, C. Lipizzi, M. Kamil, S. Manchanda. 2014. “Summary of Findings from the Helix Project (2013-14) - An Investigation of the DNA of the Systems Engineering Workforce”. Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, Springfield, VA, USA, October 28-30, 2014.

Henry, D., N. Hutchison, A. Pyster. 2015. “Summary of Findings from the Helix Project (2013-2014): An Investigation of the DNA of the Systems Engineering Workforce.” Proceedings of the National Defense Industrial Association (NDIA) Systems Engineering Conference, October 29-November 1, 2014, Crystal City, VA.

Hutchison, N. 2017. *Atlas: A Guide to Growing Effective Systems Engineers*. Proceedings of the Institute for Industrial and Systems Engineers (IISE) Conference, 20-23 May 2017. Pittsburgh, PA, USA. IISE 2017 Conference #2546.

Hutchison, N. 2015. *A Framework to Classify Experiences and Enable Career Path Analysis to Support Maturation of Effective Systems Engineers in the Defense Industry*. PhD Dissertation. Hoboken, NJ: Stevens Institute of Technology. October 2015.

Hutchison, N. and A. Pyster. 2015. “The Helix Project: Analysis of INCOSE SE Certification Program Applicants.” Presentation to the INCOSE Corporate Advisory Board, INCOSE International Workshop, January 2015, Los Angeles, CA.

Hutchison, N., A. Pyster, D. Henry. 2017. "Atlas: Understanding What Makes Systems Engineers Effective in the US Defense Community." Systems Engineering. Expected to be published 2017.

Hutchison, N., D. Henry, A. Pyster, and P. Dominick. 2014. “Systems Engineering Career Analysis: Supporting a Theory of Systems Engineers.” Proceedings of the INCOSE Europe, Middle-East, Africa Systems Engineering Conference (EMEASEC), Cape Town, South Africa, October 27-30, 2014.

Hutchison, N., D. Henry, A. Pyster, P. Dominick. 2014(b). “Systems Engineering Career Analysis: Supporting a Theory of Systems Engineers.” Proceedings of the Europe, Middle East, and Asia Sector Systems Engineering Conference, 27-30 October 2014, Cape Town, South Africa.

Hutchison, N., D. Henry, A. Pyster. 2014(a). “Early Findings from Interviewing Systems Engineers Who Support the US Department of Defense.” Proceedings of the International Council on Systems Engineering (INCOSE) International Symposium, 30 June – 4 July 2014, Las Vegas, NV.

Hutchison, N., D. Henry, A. Pyster, R. Pineda. 2014. “Early Findings from Interviewing Systems Engineers who Support the US Department of Defense.” 2014 International Council on Systems Engineering International Symposium, June 30-July 3, 2014, Las Vegas, Nevada.

Hutchison, N., J. Wade, S. Luna. 2017. “The Roles of Systems Engineers Revisited.” Proceedings of the 27th Annual INCOSE International Symposium, 15-20 July 2017, Adelaide, Australia.

Jauregui, C., A. Pyster, D. Henry, N. Hutchison, and C. Wright. 2016. “Insights on the Experiences and Education of INCOSE-Certified Expert Systems Engineering Professionals and Chief Systems Engineers.” To be published in the Proceedings of the International Council on Systems Engineering (INCOSE) 26th International Symposium, 18-21 July 2016, Edinburgh, Scotland.

Lipizzi, C., S. Manchanda, M. Kamil, A. Pyster, D. Henry, N. Hutchison. 2015. “The Education Background of INCOSE Systems Engineering Professional Certification Program Applicants.” Proceedings of the International Council on Systems Engineering (INCOSE) International Symposium, Seattle, WA, July 2015. (Accepted for publication)

Pyser, A., S. Rifkin, D. Henry, K. Lasfser, N. Hutchison, D. Gelosh. 2013. "The Helix Project: Understanding the Systems Engineers who Support the US Department of Defense." Asia-Pacific Conference on Systems Engineering (APCOSE), Yokahama, Japan, Sept. 8 - 11, 2013.

Pyster, A. 2015. “The Helix Project: Analysis of INCOSE SE Certification Program Applicants.” Special Presentation to the International Council on Systems Engineering (INCOSE) Corporate Advisory Board (CAB), January 25, 2015 as part of the INCOSE International Workshop, January 25-27, Los Angeles, CA.

Pyster, A., D. Henry, N. Hutchison, C. Jauregui, J. Armstrong, M. Clifford. 2015. Report on the Second Helix Workshop: Exploring the Theory of Systems Engineers’ Effectiveness. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology.

Pyster, A., N. Hutchison, D. Henry, C. Barboza. 2015. “Helix: What Makes Systems Engineers Effective?” Proceedings of the Conference on Systems Engineering Research (CSER), March 17-19, 2015, Hoboken, NJ.

Pyster, A., R.L. Pineda, D. Henry, N. Hutchison. 2013. Helix – Phases 1 and 2. Hoboken, NJ: Systems Engineering Research Center, Stevens Institute of Technology. SERC-2013-TR-038-2.

Squires, A., Wade, J., Hutchison, N. 2016. “Building a Pathway to Systems Education for the Global Engineer.” To be published in the Proceedings of the American Society for Engineering Education (ASEE) 123rd Annual Conference, 26-29 June 2016, New Orleans, Louisiana, USA.

APPENDIX B: UPDATED INTERVIEW QUESTIONS FOR HELIX

Individually Focused

Getting to Know You

IND01 How did you get in to systems engineering?

IND02 Do you consider yourself a systems engineer?

IND03 Define your current position.

IND04 How would you rate your own clarity about your role as a systems engineer right now – high, medium, or low clarity? Why?

Exploring Organizational Characteristics

GRP01 How do systems engineers integrate into teams here? (What is the day in the life of a systems engineer like with respect to who they work with and what they do together?)

GRP02 How do you think others on your team would rate the clarity of your role as a systems engineer right now – high, medium, or low clarity? Why?

GRP03 We are going to do some free word associations. This is when I say a word or phrase and you write down, without filter, the first three things that come to mind. Let's practice aloud: apple; car. OK, so thinking about your experience **in this organization**, please write down the first three words that come to mind when I say each phrase [worksheet for participants]: systems engineering; systems engineering management; senior leadership; [organization name].

GRP04 Draw a picture that shows how systems engineering is really done here, in your experience.
(Follow up: Thinking about the culture of the organization, what aspects of "the way we do things around here" contribute to SE growth and success and which hinder SE growth and success here?)

GRP05 How would you describe the status of systems engineering in this organization? What is your rationale? (Follow up: Are systems engineers considered leaders?)

GRP06 What kinds of decisions are highly influenced or "owned" by systems engineers in this company?
(Follow up: Are there any kinds of decisions where you are not at the table and think systems engineers should be involved?)

GRP07 When you think of systems engineering as a profession, would you say you feel very connected, moderately connected, slightly connected or not connected to the broader systems engineering community? Why do you say that?

GRP08 What's changing in your organization and what role do SE's have in driving those changes?

GRP09 How do you think that the nature of the work you do influences your approach to systems engineering?

GRP10 How do projects get staffed?

Organizational Change

ORG08 If you could change one thing in this organization that would improve your systems engineering capabilities, what would it be? [Note: time/money/power are not an issue.]

<u>Organizationally Focused</u>

ORG01 What is Systems Engineering?

ORG02 What does the organization value about systems engineering?

ORG03 Where does systems engineering fit in the organizational structure?

ORG04 How does the organization expect systems engineers to be integrated into its engineering teams?

ORG05 What is the management style in the organization? How is the SE workforce included in the management process?

ORG06 What practices does the organization currently implement to minimize systems engineering turnover? (i.e. retention incentives, career development options)

ORG07 Is there a gap between the skills of your systems engineering workforce and your organizational need? (Follow up: What are you doing to fill that gap?)

ORG08 If you could change one thing in this organization that would improve your systems engineering capabilities, what would it be? [Note: time/money/power are not an issue.]

APPENDIX C: CULTURAL CHARACTERISTICS – DEFINITIONS AND RELATED QUESTIONS

1. Status afforded Systems Engineers (High, Low, In Transition)

- Perceived by SEs
- Espoused as valued by leadership in Annual Reports and company docs
- Formal availability and actual use of systems engineering rewards
- Examples of informal recognition
- Key leadership roles filled by Systems Engineers

2. Structure (SE Functionally Centralized vs. Distributed – Matrix, Function, Project)

- Evidence of managing the polarities of both functional and distributed structures: strong functional support (training, mentoring, career ladders) and strong cross-functional collaboration (integration in project teams, cross-business contributions)

Strong Matrix Organization Structure

- In strong matrix organizations, most of the power and authority is held by project managers. Project managers have a full time role, have a full time project management administrative staff under them and control the project budget. The strong matrix structure has a lot of the characteristics of a "projectized" organization.
- The functional manager will have a very limited role within the Strong Matrix Organization.

Balanced Matrix Organization Structure

- In balanced matrix organizations, power and authority are shared between the functional managers and the project managers. Although project managers have a full time role, they have a part time or otherwise limited project management administrative staff under them. In this type of structure, both managers control the project budget.

Weak Matrix Organization Structure

- In weak matrix organizations, project managers will have limited power and authority. They will have a part time role and no administrative staff will report to them. Their role will be more like a coordinator or an expediter. Here, the functional manager controls the project budget.
- A weak matrix organization structure resembles the characteristics of a functional organization structure.

3. Professionalism (High, Low, In Transition)

- Self-Regard: self-reported pride in functional expertise and contributions, participation in industry SE groups
- Other-Regard: encouraged to submit papers and participate in industry groups by leadership, budget for professional activities
- Other-Regard: Viewed by non-systems engineering colleagues as acting in integrity with systems engineering values and ethics

4. Role Formality (High, Low)

- SEs do prescribed job applying prescribed skills vs. SEs fulfill multiple roles, some of which are not related to systems engineering
- Degree of specificity of roles
- Degree of shared understanding or clarity about roles
- Types of SE training, rotations, mentorships, apprenticeships, ladder, titles, hiring

5. Influence (High, Low)

- Reach (narrow – broad)
  - Within team, cross-functional, cross level, cross company
- Decision Ownership
  - Which decisions do they own? Which do they contribute to? From which are they excluded?

6. Collaboration (High, Low: Strength, Breadth)

- Team participation
  - percent of time? co-location/ distance collaboration: time/support for
  - act as team leaders, members or "SME consultants" (structure?)
- Types of cross-functional daily work
- Types of joint learning, e.g., participation in after-action reviews
- Diversity of team membership (functions, levels, customer involvement…)
- Self-described and company-espoused values re: teamwork, joint problem solving and conflict resolution, group creativity and innovation

7. Change

- What formal initiatives are ongoing?
  - Who sponsors them? Who participates?
  - Roles of SEs and SE Leaders in the change?
  - Links to corporate or SE strategies?
  - What organization, function, culture or process change initiatives do SEs sponsor or lead?
- Informal change
  - Do SEs and Non-SEs view SEs as champions for change (possible areas: best practices, teaming, communication, technical innovation…)